

# ***New and Emerging Renewable Energy Opportunities***

***in New Zealand***





# **NEW AND EMERGING RENEWABLE ENERGY OPPORTUNITIES IN NEW ZEALAND**

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and



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**Cover**

A representation of some renewable energy sources. Against a background of plantation forestry indicating biomass, are pictures of (top to bottom) the recently constructed Hau Nui wind farm, roof solar panels, and the Hinemaiaia 'C' small hydro project near Taupo.

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It will be noted that the authorship of this document has been attributed to a number of individuals and organisations involved in its production. While all sections have been subject to review and final editing, the opinions expressed remain those of the authors and do not necessarily reflect the views of the Energy Efficiency and Conservation Authority or the Centre for Advanced Engineering. Recommendations need to be interpreted with care and judgement.

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# Foreword

I welcome this report on the current status of new renewable energy technologies in New Zealand.

Its publication is timely, as it comes when a range of new renewable energy developments are starting to flourish. Recently I have attended openings of a landfill gas plant in Silverstream to generate electricity, a landfill gas project at Green Island which will meet most of Dunedin's reticulated gas needs and New Zealand's first commercial wind farm in the Wairarapa.

These, and other similar developments, are part of the future for New Zealand's energy supply. Small, innovative technologies, close to load centres, environmentally benign - what a far cry from the remote, monolithic, environmentally disruptive plants that we have seen in the past.



Without doubt the Government's recent energy sector reforms have improved the conditions for developing renewable energy options here in New Zealand. The introduction of a competitive environment and the electricity market reforms have opened access to transmission facilities and are improving pricing signals. The establishment of the Energy Efficiency and Conservation Authority has resulted in some good work focusing on the barriers to and opportunities for renewable energy, as is evidenced by the work within this report. In addition, the Government is examining its options for reducing greenhouse gas emissions due to national and international concern about the threat of climate change.

Renewable energy technologies have a crucial opportunity to exploit these changes. It is clearly recognised that New Zealand has excellent conditions for renewable energy. However, the availability of a resource alone does not guarantee commercial success. Progress on market reforms has opened the way for new generators to come into the market. It is particularly pleasing for me to see the number of renewable energy proposals appearing as part of the mixture of new generation. Early 'pioneer' projects will make it easier for those which follow, as increased familiarity with operating conditions and the market environment builds confidence in the future.

In addition there are some innovative and entrepreneurial projects progressing to pilot stage. As a result of the continuing improvement in the economics of renewable energy technologies I expect to see an even wider range of projects emerge to become part of the New Zealand energy landscape.

With New Zealand's excellent renewable energy resources, we need to apply our minds to the state of the technology and the likely paths forward for harnessing these resources. Technology continues to advance and costs are still coming down, as I have seen in visits to the United States and more recently to Europe. We need to continue to assess the resource, technologies, economics and impacts.

This report amalgamates the current industry and research knowledge on New Zealand's present and possible future renewable energy opportunities. Therefore, it should be a useful resource for all levels of decision makers, and for the public in general. The public's interest and support for renewable energy will be informed by readily available, reliable and current information. This in turn will help the renewable energy industry build a positive future.

It is also hoped that financiers, investors and developers will find this a useful reference source about the current state and future potential of the 'new renewables' industry. As this industry emerges there is growing interest in early investment - a reflection of the worldwide trends as renewable energy costs reduce.

I also wish to acknowledge the wide range of contributors to this report. Commitment to this project came

from the project teams in EECA and CAE, as well as the co-sponsors ECNZ, the Ministry of Commerce and the Ministry for the Environment. In addition, many of New Zealand's renewable energy experts 'peer reviewed' and offered comments on this document. Many other interested organisations and individuals also committed time to the process.

It seems clear from the information gathered that renewable energy will continue to play a significant role in New Zealand's energy future. I am sure this report will help to inform public understanding, assist planning and stimulate further interest. To meet the energy needs of the community (and individuals) in a sustainable way requires a national, local and personal commitment. I feel a sense of pride to have seen the emergence of a renewable energy industry during my time as Energy Minister and I wish the industry a bright, sustainable future.

**Hon Doug Kidd**

**Minister of Energy**

July 1996



# Preface

The Energy Efficiency and Conservation Authority (EECA) in association with the Centre for Advanced Engineering, University of Canterbury (CAE) began the initiative to produce this report on New and Emerging Renewable Energy Opportunities in New Zealand. The project has also been supported financially by the Electricity Corporation of New Zealand (ECNZ), the Ministry for the Environment (MfE) and the Ministry of Commerce (MoC).

The 1993 report “Renewable Energy Opportunities for New Zealand”, prepared by a number of authors, edited by Eden Resources Ltd and published by the Ministry of Commerce, was taken as the starting point. It had been prepared under major constraints of time and resources but proved very successful in stimulating debate and providing a reference document by bringing together the available information.

The target readership for this report is assumed to be stakeholders from a broad range of backgrounds and will include financiers, investors, developers, policy makers, educators, lobbyists, research providers, consultants and members of the energy industry in general.

In contrast to the 1993 renewable energy report, large to medium scale hydro power schemes (over 10 MW installed capacity) and geothermal energy were omitted from this report, being relatively mature technologies already extensively used in an economically competitive energy environment. It was recognised that further gains in efficiency for medium- to large-scale hydro and geothermal energy are yet to be made and some new developments may be initiated. However, the focus of the report was placed on the “non-traditional” renewable energy technologies likely to become feasible to apply in New Zealand within the near to medium future.

This omission is not intended to in any way downplay the importance of considering large to medium scale hydro power and geothermal energy in New Zealand’s future energy requirements over the next 10 to 15 years. Over this timescale, energy supply from other sources (e.g. natural gas) may diminish, become more expensive or face increasing international pressure to limit carbon dioxide emissions. Such factors are likely to make a variety of renewable energy sources increasingly attractive.

This latest EECA/CAE report is more than an update of the 1993 report. It draws extensively on the considerable activity in renewable energy technologies which has occurred since 1993, and includes the latest developments in what is becoming a rapidly growing international industry. Since 1993, new resource opportunities have arisen, the implications of the Resource Management Act (1991) have become better understood, renewable energy technologies have advanced and become more competitive, and international agreements to reduce carbon dioxide emissions from fossil fuel use have been given a greater government priority in many countries including New Zealand. On a more local level, regional and district plans have been produced in which renewable energy has been increasingly recognised. In addition, some planning consent applications relating to renewable energy proposals have been evaluated by regulatory authorities, giving a better indication as to what developments may be approved.

## ***The Process of Compiling the Report***

For the first draft of this report, prominent specialists in each topic section area were invited to prepare a paper. Where feasible, alternative authors to those involved in the Ministry of Commerce 1993 report were approached. The draft papers were then bound and pre-circulated to eighty delegates who attended a one-day seminar held in Rotorua on 11 March 1996.

During the seminar, four concurrent workshops were held — on solar, biomass, water and wind energy systems — facilitated respectively by Mr Ken Piddington (Sustainable Energy Forum), Mr Frank Pool (EECA), Mr Erin Roughton (EECA) and Ms Fiona Weightman (EECA). Senior authors briefly presented the key points of their papers, short additional papers were presented, and contributions from all delegates present were then invited during structured discussion periods. The key issues were noted, and the senior authors given the opportunity to subsequently amend their original draft papers accordingly. The contributions from all participants are acknowledged at the beginning of each section of this report.

The project manager, Ralph Sims (Massey University) assisted by Chris Collins (Eden Resources Ltd) then edited the papers into a logical sequence and incorporated additional significant material.

The report resulting from this process is therefore a compilation of the views and experience of many people with extensive knowledge in their specialist areas. Where an issue was debated at a workshop but a consensus was not reached, the opposing views are noted in the text.

In the growing renewable energy industry, there is still much to learn. It is intended that this report will increase the knowledge, raise the awareness of opportunities and encourage future development of the new and emerging renewable energy technologies in New Zealand.

**J P Blakeley**

**Executive Director**

**Centre for Advanced Engineering**

**UNIVERSITY OF CANTERBURY**

July 1996

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**Energy Efficiency and Conservation Authority**



**Centre for Advanced Engineering, University of Canterbury**



**Electricity Corporation of New Zealand Limited**



**Ministry for the Environment**



**Ministry of Commerce**

## *Technical Contributors*

Many people have made technical contributions to the preparation of this report. Individual contributors are identified at the beginning of each section and their input was essential to the successful outcome of the project. A great deal of this input has been given on a voluntary basis which is greatly appreciated.

The major contribution in the preparation of this report made by **Associate Professor Ralph Sims** (Massey University) as Project Manager assisted by **Mr Chris Collins** (Eden Resources Ltd) is particularly acknowledged.

# ***Conversion Factors***

k	(kilo)	$10^3$	thousand
M	(mega)	$10^6$	million
G	(giga)	$10^9$	thousand million
T	(tera)	$10^{12}$	million million
P	(peta)	$10^{15}$	thousand million million

1 kWh  $\equiv$  3.6 MJ

1 PJ  $\equiv$  280 GWh or 0.28 TWh

# ***Executive Summary***

Renewable energy sources, such as hydro power, already make a significant contribution to New Zealand's total primary energy demand. This report considers the present status and future opportunities for new and emerging renewable energy technologies in New Zealand within the next decade.

Renewable energy resources are energy sources that can be tapped at a rate which allows them to be replenished, through natural processes, so that utilisation is countered by regeneration. Renewable energy developments harness energy for human benefit from these continuous energy flows. The underlying sources of most renewable energy are the sun, the action of gravity, the earth's rotational forces and internal temperature. The main energy carriers are the wind and ocean processes; the fall of water from lakes and rivers; contemporary biomass or plant materials and animal and human wastes.

Large scale hydro schemes and geothermal projects represent mature technologies, well established and extensively deployed within New Zealand. It is acknowledged that some technical refinement and innovation is still occurring with these two renewable energy sources. This report, however, reviews technologies applicable to those renewable energy resources that have not been widely used in New Zealand to date. These technologies are defined as 'new and emerging renewable energy technologies' and they include the following:

- Solar thermal;
- Passive solar building design;
- Photovoltaic;
- Other solar conversion systems;
- Woody biomass;
- Energy crops;
- Energy recovery from wastes;
- Small hydro (less than 10 MW);
- Wave, tidal and ocean currents;
- Wind; and
- Integrated energy systems.

A brief introduction on each technology and a commentary on significant technology changes within the last few years is provided in Section 1.4.

The emphasis of the report is on electricity generation and the provision of medium and low grade heat. The production of alternative transport fuels is discussed to a lesser degree (in the appropriate sections) since this is unlikely to prove economic within the ten year time frame.

## ***Technology review***

- Many of the renewable energy technologies likely to be commercial in New Zealand within the next ten years are already being demonstrated or used commercially somewhere in the world. Examples include wind turbine technologies and new solar thermal conversion systems.
- Other technologies which may be able to compete with conventional energy supplies in the future, such as photovoltaic conversion, are the subject of concerted research and development programmes, or are at the even later stage of trials to establish economic mass production techniques.
- World wide investment in several of the new and emerging renewable energy technologies is increasing



as improvements in design and operation result in cost reductions. To be applicable to New Zealand these technologies may require local trials and adaptation.

- There is no shortage of appropriate technology or expertise in New Zealand, including the ability to tap into overseas knowledge, and therefore access to information per se should not be a constraint to any future development. It is not clear, however, that the subsequent dissemination of information to all potential users is extensive or rapid enough.
- The systems considered in this report are likely to be developed at the relatively small to medium scale (1 kW to 50 MW). This scale reflects the congruence of commercial considerations and the distribution and magnitude of the renewable sources or, such as in the case of passive solar house design, the size of the end-use energy demand.
- Most new renewable developments are modular and, therefore, flexible in application. They can match the available size of the energy resource, meet local energy demand and site specifications, allow for future expansion and, ultimately, be removed at the end of their operating life.
- New renewable energy resources are very well suited to development as embedded or distributed generation, or for stand alone remote area power supplies (RAPS). One of the major commercial advantages of new renewable technologies is the avoidance of transmission or distribution system capital investment and energy losses.
- Several types of new renewable energy resource can be developed into an integrated system — for example the use of wind, micro-hydro and a small water storage basin — in a way that overcomes the limitations of any one of the resources on its own.
- Synergies also exist between various types of new renewable energy sources and traditional heat and power sources (potential examples include as co-firing of fuelwood and coal, using wind power to conserve large hydro lake storage levels, and blending ethanol with petrol). Harnessing these synergies would encourage greater use of new renewables and also to engender greater confidence in their performance.
- The new renewable energy technologies which are most likely to make an increased contribution to New Zealand's primary energy supply within the next decade are; biomass in the form of wood processing residues, domestic firewood supplies and forest arisings; wind power via wind farms; and new small hydro schemes.
- Passive solar design could also make a significant contribution to reducing the energy demand in buildings, particularly if social barriers to its adoption are addressed. At the end of the ten year time frame it is possible that photovoltaic conversion technology will become viable for general household use and will start to be more widely used.
- New biomass conversion technologies, possibly using purpose grown crops, may also become commercially viable within the next ten years.

## ***New Zealand experience***

- Around 30% (128 PJ) of New Zealand's energy is supplied by renewable resources. Direct heat from renewable sources, mostly from biomass and to a lesser extent from geothermal resources, contributes 11% of the country's energy supply. The remaining renewable contribution, namely 19%, is in the form of electric power. Hydro contributes about 70% of all electricity generated, including that from thermal power stations, while geothermal sources provide 5% and less than 0.1% comes from new renewable resources.
- Hydro power presently accounts for approximately 5000 MW of electricity generation capacity, of which 126 MW (2.5%) is from small hydro power stations of less than 10 MW capacity.
- Biomass, in its many forms, currently provides over 4% of the total national primary energy supply, or approximately 28 PJ per year (mainly in the form of heat).

- New Zealand has a well established domestic wood burner industry with local manufacture and an extensive and competitive network of wood supply merchants. Significant use is made of wood processing residues, such as bark, by the timber and pulp and paper industries.
- Buildings designed for passive solar heating are becoming more popular. Many examples of solar water heating exist, and small scale photovoltaic systems are in use to supply power to remote applications.
- The first wind farm (Wairarapa Electricity's 3.5 MW Hau Nui wind farm) is now operational and others have received resource consents, are going through the Resource Management Act process or are being planned.
- There are many examples of small independent energy supply systems operating, particularly in remote locations, which provide collectively thousands of kilowatts of power.
- Overseas technology can seldom be directly applied in New Zealand without adaption to local conditions. Overseas technologies generally need to be evaluated in New Zealand prior to application. This may often require a significant research and development effort.
- In New Zealand the national electricity grid transmits large amounts of power over long distances which results in energy losses and a vulnerability to natural hazards. In addition, the future expansion of the grid could meet various constraints. These problems can be reduced by developing new renewable energy resources close to the point of demand.

## ***The New Zealand renewable energy resource***

- New Zealand has a set of climatic, geographic and other factors which tend to make conditions favourable for many specific renewable energy applications.
- The country has abundant resources of wind, rainfall and sunshine. It has a long coastline, steep rivers and streams, and elevated lakes. The climate and soils are favourable for agriculture and there is land available for energy crops and forestry.
- Geographically New Zealand lies on a north-east, south west axis in mid-latitudes and across the prevailing winds. It also has ample coastal land and elevated sites. Consequently New Zealand has a wind resource that would be envied by many other countries. The technology is available to develop this resource now.
- The location of the country also means that its coastal and near off-shore waters receive a massive amount of wave energy. Technologies are not yet available to reliably tap this energy source and commercial plant will probably not be developed within the ten year time frame. In the longer term this resource could become important.
- In terms of both magnitude and potential for medium term realisation, biomass energy stands out. New Zealand has a very large and increasing exotic forest resource which will produce a substantial resource in the form of arisings and processing residues. While there will be demand for this material as a fibre source, it is likely that a large amount will be available as a potential energy source.
- The country also has a large amount of land suitable for growing crops and establishing short rotation tree plantations with energy production as the main or a subsidiary purpose.
- New Zealand has a temperate climate and a good level of sunshine. This means that the energy needed in a well designed home, to provide space and water heating, is not great compared with that which is readily accessible to the home from passive solar, solar thermal and photovoltaic conversion. Consequently, toward the end of the ten year time frame, it is conceivable that new homes almost self sufficient in energy will appear.
- New Zealand's potential new renewable resources are widely and reasonably evenly distributed throughout the country. Furthermore, while there is large population concentration within the Auckland region, there are reasonable large population centres well distributed through both North and South Islands. This facilitates a match between new renewable energy supply and local demand.

- New Zealand has some major energy intensive industries, but its low population means that its total primary energy demand is relatively low compared to other developed nations with a similar land area (Great Britain for example). In the longer term, given New Zealand's abundant sustainable natural resources and low population, renewable energy has the potential to become the major source of primary energy for the country.
- In one sense resources are only meaningful if people have the will and means to use them. New Zealand has the research, survey and development infrastructure needed to use its potential new renewable energy resources. Furthermore New Zealanders as a whole tend to be well educated, innovative, and generally supportive of positive environmental initiatives — such as the greater use of renewable energy.

## ***Environmental aspects***

- There is considerable concern that the documented increase in atmospheric levels of greenhouse gases, particularly carbon dioxide, may be bringing about accelerated climate change. Climate change more rapid than historic rates could severely stress natural processes and ecosystems and the human economic and social systems that depend on these.
- As a signatory to the Framework Convention on Climate Change, the New Zealand Government is already committed to policy action on decreasing greenhouse gas emissions and enhancing sinks, such as forests. Greater renewable energy use and further energy efficiency measures are two of the key means for reducing carbon dioxide emissions.
- The international environmental debate over the appropriate choice of electricity generating systems is also evoked by matters other than climate change concern. Both site specific changes and more extensive ecological and social impacts may be at issue with conventional energy sources (thermal, large hydro and geothermal). Conventional thermal power generation, for example, can create local air pollutants, such as nitrous oxides, and trans-national problems, such as sulphur emissions leading to acidification of forests and lakes in adjacent countries.
- As another example, large scale hydro electric developments, located in major catchments, can evoke concerns across an extensive geographic area. These concerns can range from inundation of farming land, effects on land stability, relocation of people, loss of habitats and other resources. Similarly, geothermal developments raise a wide range of concerns (for example over water quality and, in New Zealand, on Treaty of Waitangi issues).
- New renewable energy projects also have impacts on the environment. However, due to the small scale and character of these projects, the impacts tend to be of a more local nature compared with the impact of conventional technologies. Possible detrimental impacts include the local effects of air emissions, visual amenity changes and habitat loss. The actual impacts for a project will be site and technology specific but there will be generally opportunities for mitigation.
- Furthermore the small scale and modular nature of most new renewable technologies means many effects are reversible. A wind farm for example can be built, used and decommissioned with little permanent change to the site's long term ability to provide other forms of amenity.
- The disposal of wastes, such as animal effluent from farms, industrial residues, or municipal refuse, is both costly and creates environmental impacts. The recovery of energy from wastes, using well designed and managed systems, may be cost effective, may reduce overall environmental impacts and, in some cases, produce useful co-products.
- The absence of a national policy statement on carbon dioxide emissions is argued by some in the renewable energy industry to create difficulties when seeking, under the Resource Management Act for example, to have the climate change benefits of a renewable energy project balanced against its potentially adverse local environmental effects.
- Early identification of any potential environmental concerns must be an integral part of project planning for new renewable energy development. There should be full and early consultation about these impacts and the potential for mitigation with the local communities and the relevant territorial authorities.

## Social aspects

- For the same power output there are generally greater employment opportunities from the increased development of renewable energy technologies compared to fossil fuel supply options. This is due to the different economies of scale and the ability to develop an extensive local support infrastructure.
- Rural communities, in particular, can benefit from local renewable energy through employment opportunities, greater security or quantity of power supply, and cheaper overall electricity prices, especially where the cost of supplying or maintaining distribution lines is high.
- Catastrophic failure of a new renewable project, due to natural hazards such as earthquakes, is not likely to create the same level of social disruption as that of a major thermal power station or large hydro-electric dam.
- Greater renewable energy utilisation can enhance the green image of New Zealand often portrayed overseas, with benefits to tourism and trade.

## Economics

- A summary of current wholesale fuel production and electricity generation costs for the main forms of renewable energy is given below. These are 'best estimates' and therefore can only be regarded as indicative. Wide variations occur due to the site specific variables such as mean annual wind speeds, transport distances, scale of projects, crop yields etc. Hence the figures only provide approximate comparisons with current conventional energy costs. Detailed site specific analyses would need to be undertaken to establish accurate costs for individual renewable energy projects.

Note: The cost estimates include transmission charges where appropriate.

A discount rate of 10 % was used where appropriate (see the discussion in the Renewable Energy Opportunities report, Ministry of Commerce, 1993).

### Solar

Solar thermal for water heating	13 - 16 c/kWh.
Passive solar for space heating	varies considerably, but can be as low as 1 c/kWh.
Photovoltaics	30 - 60 c/kWh (probably falling to 15-20 c/kWh by 2005).

### Biomass fuels

Forest arisings	\$3 - 8.7 / GJ
Wood process residues	\$0 - 6.4 / GJ
Short rotation plantations	\$1.6 - 5.0 / GJ
Firewood	\$2.6 - 20 / GJ (can be lower if labour not costed in)
Energy crops	\$0.6 - 8.0 / GJ (yield and product dependent)
Municipal solid waste	\$3.2 - 5.6 / GJ (based on tipping and transport costs)

### Bioenergy conversion costs

For conversion to heat add \$2.50 - 3 / GJ to the fuel cost for delivered heat cost.

Conversion to electricity at the 5 - 100 MWe plant scale:

For fuel cost @:	\$0/GJ	7 - 9 c/kWh
	\$2/GJ	11 - 13 c/kWh
	\$5/GJ	14 - 16 c/kWh
	Biogas from organic wastes	2 - 5 c/kWh
	Biogas from green crops	11 - 18 c/kWh
	Landfill gas	5 - 7 c/kWh

Note that cost benefits from cogeneration opportunities have not been included.

### *Water*

Small hydro <10 MW	5 - 10 c/kWh (315 MW capacity available)
	10 - 15 c/kWh (470 MW capacity available)
Tidal	>30 c/kWh
Wave	>50 c/kWh

### *Wind*

Wind farms on best sites	6 - 8 c/kWh.
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### *Renewable energy hybrid systems*

Small scale PV/wind systems	30 - 60 c/kWh
Micro-hydro	17 - 30 c/kWh

## **Constraints**

- Some renewable energy technologies are currently commercial in niche markets. However, others will require further research, development and demonstration before they become competitive. Some renewable energy technologies are unlikely to become commercialised within the ten year time span of this report.
- The cost of energy from conventional sources in New Zealand remains relatively low and predictions for the short term do not indicate significant increases. For example, relatively low gas prices combined with the improved efficiency of gas use in planned combined-cycle power stations will help to minimise electricity price rises. Sustained low prices could restrain the uptake of renewable energy.
- The current price of energy from fossil fuels does not include the environmental externality costs of extracting and burning the fuels. New renewable energy developments create either negligible, or far less net carbon dioxide emissions than fossil fuel use, for example. A case can be made for reflecting this factor in the price of energy from different sources.
- While renewable energy projects tend to have low operating and maintenance costs, they tend to require a high initial capital investment. This high 'up-front' cost means that, when compared to conventional technologies, the commercial viability of renewable energy projects is more sensitive to the discount rate used in the financial assessment.
- The discount rate applied to new renewable energy projects can be high due to lack of familiarity with the technologies by investors and the absence of an industry with a proven track record.
- The pricing regime for national grid transmission costs for electricity may have a significant impact on the future economic viability of certain renewable energy projects. Transmission costs faced by a power company are based on its historic use of the grid and only decline gradually (over many years), in response to substantial reduction in electricity imports. The advantages to a power company of an embedded energy project, which avoids the use of the grid, are eroded by the inertia in the grid charges.
- Where renewable energy projects are only able to provide power intermittently (usually due to dependence on the weather) and do not have associated energy storage, a back-up supply will usually be required. The back up supply can be obtained via the grid or from an embedded source. Transmission pricing regimes and the costs of a back-up supply may affect the economic viability of the renewable energy project. The alternative to a back up supply, namely gaining customers whose supply can be interrupted, also involves a financial penalty.
- Attitudes towards specific renewable energy projects may be conservative, not just among the general public but also among professional people, including architects and engineers engaged in design and specification of structures. Widespread experience of renewable energy projects will be required before their performance can be understood as readily as those of the conventional technologies.
- Available energy resource information is often inadequate to allow developers to make informed decisions



to progress an individual project. The cost of gathering resource data can be a major component of a project's upfront costs. In some cases the data required for a single project has wider application but it is difficult for the developer to capture the benefits of this public good.

- General lack of public familiarity with some new renewable technologies means that a high level of information dissemination and consultation is required during the Resource Management Act process. The need for the first few projects to address all possible issues exhaustively, adds costs and reduces project margins.
- Passive solar design of buildings is poorly understood and its principles need to be promoted so that all design professionals can recognise opportunities for incorporating solar gain features in their projects.
- Solar heating of domestic hot water, in most cases, has a longer payback period than conventional electricity or gas options, and many consumers are not willing to accept this longer period.

## **Opportunities**

- Many members of the community appear to support greater emphasis on renewable energy supplies in order to achieve a more sustainable future. For example, based on a recent survey, there is a willingness by up to one third of consumers to pay a premium for "green energy" supplied by renewable energy. The challenge is to find ways to tap this willingness.
- In recent years increased concern about the environment, in particular the impacts of conventional energy systems, has focused interest on renewable energy. The impacts of new renewable technologies are generally limited in extent and amenable to mitigation and consequently they are seen to be a solution to the problems of conventional systems.
- The New Zealand Government is already committed to policy action to reduce projected carbon dioxide emissions. The Working Group on Climate Change, whose report was released on 20 June 1996, has suggested that an economic instrument (carbon charges or tradeable carbon certificates) will provide the least cost means of reducing emissions. Adoption of such an economic instrument is likely to increase the cost of heat and power derived from fossil fuels, and this may improve the commercial viability of new renewable energy projects.
- Internationally there has been a rapid decrease in the capital costs of many new renewable energy technologies through manufacturing innovations. Furthermore improvements in energy conversion efficiencies have also lowered the cost of heat and power from these technologies. Consequent increases in production have also helped reduce prices through economies of scale.
- The approaching depletion of the Maui gas reserves may encourage the development of alternative energy supplies, including new renewable energy sources.
- Growth in demand for electricity could place pressures on the existing national electricity transmission grid. Greater use of locally based new renewable energy sources could be one of the responses to these pressures. Embedded or distributed generation could reduce the level of commercial risk involved and the investment required to maintain and upgrade the transmission networks.
- The high quality, ready availability and magnitude of new renewable energy resources in New Zealand mean that they are not easily overlooked. Developing these resources can make a significant contribution to regional energy supply and demand balances and to the overall proportion of renewable sources as part of the country's primary energy supply mix.
- The high quality of New Zealand's renewable energy resources and the opportunities they afford may make it attractive to develop leading edge capabilities in the design of technologies (for example, high speed wind turbines). Developing leading edge technologies could open up significant export market opportunities (for example in South East Asia).
- Some international finance and insurance companies are reassessing their position on investments and insurance cover for projects which compound global warming and other environmental problems.

Consequently there may be increased interest in financing new renewable energy projects since these create less net greenhouse gas emissions and cause less extensive ecological impact than conventional heat and power sources.

## **Future research**

- The success of new and emerging renewable energy industries depends on continued scientific development as well as their economics in the marketplace.
- While New Zealand can benefit considerably from overseas research and development, there is often a need to trial overseas technologies and adapt them to local conditions. In some fields of research, such as exotic forest management, New Zealand has special expertise and natural advantages. This will be particularly helpful when adapting certain overseas research, but it also means that New Zealand could undertake pioneering research in selected areas.
- Local research, possibly in collaboration with overseas partners, could fruitfully focus on biomass/biofuels technologies, wind energy and solar conversion systems. Significant economic and environmental benefits could be obtained from successful research in these areas and New Zealand could realistically compete with the world's best efforts to develop the requisite technologies.
- Where there is an exceptional person or research group in a particular field they could form the core of a centre of excellence to focus New Zealand's research effort in that field. The development of such centres would be one method of progressing the country's most promising research programmes.
- Successful demonstration projects in New Zealand which can be visited and examined by the public at large would increase familiarity with the impacts of renewable energy projects. Currently there are difficulties in funding demonstration or pilot projects which fall between the status of a 'research' project (which may be eligible for public funding) and a 'commercial' project (which needs to be funded privately).

## **Conclusions**

- Concern about the environment, for example the risk of climate change from increased carbon dioxide emissions, is focusing increased interest on new and emerging renewable energy technologies.
- In the near term, new renewable energy developers should concentrate on finding suitable niche markets in New Zealand as a step towards wider commercialisation. This can be achieved by identifying opportunities that range from remote area power projects to embedded generation, by promoting projects that can substitute for transmission upgrades, and by developing synergies with conventional fuels.
- While there is no allowance in prices for the environmental externality costs of fossil fuel use, project developers should focus on the particular technologies which are economically viable at current and forecast energy prices. Building externality costs into prices in the future (either directly or indirectly) may expand the opportunities for new and emerging renewable projects.
- The new renewable energy technologies which are most likely to make an increased contribution to New Zealand's primary energy supply within the next decade are biomass, wind power, and new small hydro schemes.
- While New Zealand can benefit from overseas research, there is a need for local research and development to ensure the application of technologies to New Zealand's unique conditions.
- There are sufficient technically exploitable new and emerging renewable energy resources in New Zealand to meet the country's total energy demand in the long term (assuming it will be economic to convert a significant land area from food and fibre production to growing energy crops for transport fuels).
- The current contribution from renewable energy sources (other than large hydro and geothermal) is around

30 PJ, being approximately 5% of the total primary energy supply. A doubling of the contribution from these energy sources, that is an increase to 10% by the year 2005, appears to be a realistic possibility.

- The potential market for renewable energy technologies in New Zealand is significant. To ensure a bright future the industry players must address both the opportunities and constraints to develop a sustainable, commercial market for renewable energy technologies.

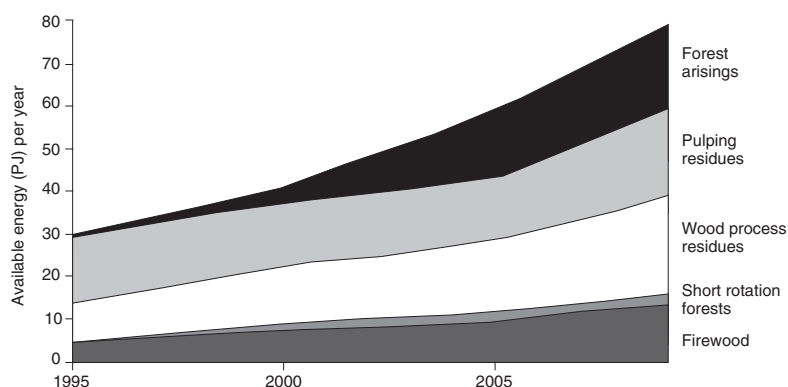
Based on the details provided in the text of this report, taking a conservative approach to the rate of technological advancements, and assuming low price increases (in the order of 1% to 2% per annum) for traditional energy supplies, an estimate for the uptake of renewable energy technologies in New Zealand by 2005 is shown in Figures 1 and 2.

#### Notes to Figures 1 and 2:

The 1995 data is based on current use information taken from the text of this report.

Energy price forecasts are based on the Ministry of Commerce report *Energy supply and demand scenarios to 2020*, July 1994.

There is a different scale for each figure.



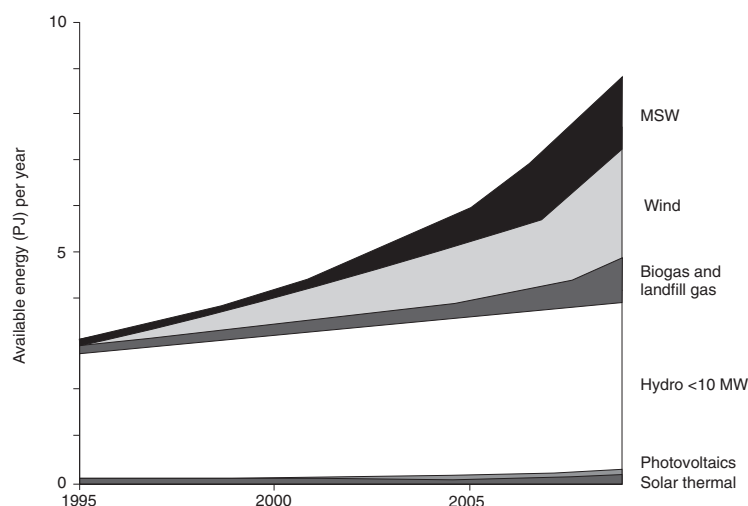
**Figure 1: Conservative estimates of primary energy supplies from woody biomass fuel**

#### Notes to Figure 1:

The Carter Holt Harvey 34 MW cogeneration plant at Kinleith is assumed to come on stream in 1997.

Pulping residue (black liquor) volumes will depend on future pulp demand and use on site.

The energy supply from short rotation forests is very difficult to predict.



**Figure 2: Conservative estimates of primary energy supplies from solar, small hydro, biogas and landfill gas, wind and municipal solid wastes**

**Notes to Figure 2:**

The Brooklyn 225 kW wind turbine is included for 1995 and the Wairarapa wind farm in 1996.

It is assumed the Tararua wind farm will come on stream in 1998.

The total contributions by 2005 from photovoltaics are likely to remain small due to their high relative costs.

Biogas and landfill gas are expected to contribute only a small amount due to the limited resource available at an economic scale.

It is assumed that landfill volumes will reduce as MSW energy recovery techniques develop.

Although passive solar already makes a significant energy contribution which is likely to increase, it was not possible to quantify what this currently is now, or might be in the future.

Alternative transport fuels, wave power, tidal power, ocean currents, high temperature solar thermal and agricultural energy crops are not included since they are unlikely to come on stream to any significant degree by 2005 at current conventional (fossil fuel) energy prices.

# 1 Introduction

## 1.1 Context

The purpose of this report is to provide up-to-date information about the technological, environmental and economic status of new and emerging renewable energy technologies. The objectives are:

- to provide a concise overview of the present technological, environmental and economic status of the renewable energy sources relevant to New Zealand; and
- to assess the potential contribution each renewable technology might make to the total energy supply by the year 2005.

It attempts to strike an appropriate balance between optimistic and conservative assessments. The report is aimed at all stakeholders and key decision makers including research providers, developers, financiers, energy suppliers, government officials, educators and lobbyists.

This report continues on from the information contained in a similar report prepared by Eden Resources for the Ministry of Commerce — *Renewable Energy Opportunities for New Zealand* (May 1993) — with the exception of large hydro and geothermal technologies.

Renewable technologies including large hydro and geothermal presently contribute approximately 80% to New Zealand's power use, with most of the remainder generated from fossil fuels such as natural gas. Currently, power demand is growing along with economic growth, although at a smaller rate due to improved efficiencies in energy use. This creates a need for new electricity generation developments in New Zealand to the order of 150 MW per year.

Recent and significant improvement in a number of other renewable energy technologies, such as wind power, woody biomass cogeneration and solar power, have led to reduced costs and increased opportunities for their commercial development. However, uncertainty and perceived higher risks of their performance continue to constrain their development. Therefore, one aim of this report is to improve understanding about these key new renewable energy technologies.

In addition, the development of renewable energy technologies is consistent with New Zealand's obligations under the Framework Convention on Climate Change, which requires a considerable reduction in projected greenhouse gas emissions. This underlines the importance of keeping knowledge on New Zealand's sustainable energy forms up to date as part of an ongoing process.

### ***New and emerging renewable energy technologies***

The technologies for harnessing renewable energy are changing rapidly and some are more likely than others to be developed commercially in the near future in New Zealand. Renewable energy technologies already contributing to the energy supply and most likely to expand in the short term include:

- small-scale hydro electric (stand-alone and grid connected up to 10 MW);
- wind power;
- solar thermal (low temperature);
- methane gas from wastes; and
- biofuels from wood process residues, domestic firewood, and incineration of municipal solid wastes.

New renewable energy technologies likely to be developed further in the medium term and produce more cost competitive energy sources include:

- biofuels from energy crops and forest arisings;



- photovoltaics; and
- wave and ocean current power.

Some of these are well advanced and at early stages of economic development. Other technologies are still at the “ideas” or conceptual stages of development, however technological or economic breakthroughs could result in accelerated development. There is a degree of uncertainty in the likely timing and progress of new renewables so it is important those technologies that could come on-stream later in the next decade are also included in this report.

## **1.2 The Renewable Energy Policy Environment**

The New Zealand Government’s policy on renewable energy is outlined in Renewable Energy: Framework Policy Statement, June 1993 which builds on the broader Energy Policy Framework, 30 June 1992.

The government’s renewable energy policy objective is:

- To facilitate the development of cost-effective renewable energy consistent with the government’s Energy Policy Framework.

The government’s over-arching policy objective for energy is:

- To ensure the continuing availability of energy services at the lowest cost to the economy as a whole, consistent with sustainable development.

These policy objectives are aimed to ensure new developments provide:

- low-cost energy;
- energy security;
- energy services accessible to all members of New Zealand society;
- a sustainable energy supply; and
- minimal adverse environmental effects.

Over recent years, reforms in a variety of areas have served to improve the environment for the development of new renewable energy supplies. The following actions were important in this respect.

- The introduction of a competitive environment for energy supply through the Energy Companies Act 1992, the Gas Act 1992, and other electricity market reform measures. These reforms continue to improve access to transmission facilities, improve pricing signals and introduce competitive incentives in the energy sector. In addition, ECNZ’s market dominance was addressed recently by splitting it into two State Owned Enterprises and imposing certain constraints such as ECNZ only being able to develop up to 50% of new generation in New Zealand. Renewable energy generation is exempt from this cap.
- The enactment of the Resource Management Act 1991 which promotes the sustainable management of natural and physical resources and is expected to lead, over time, to a greater uptake of renewable energy.
- The establishment of the Energy Efficiency and Conservation Authority (EECA) in 1992. This organisation promotes the uptake of energy efficiency, conservation and renewable energy through such measures as the dissemination of information on potential energy sources and their applications. The focus on renewable energy includes distribution of information on the economic, social and environmental impacts and the identification of further research priorities for renewable energy.
- The implementation of the CO<sub>2</sub> Reduction Programme, which incorporates specific measures to reduce emissions of carbon dioxide consistent with New Zealand’s obligations under the Framework Convention on Climate Change to stabilise net CO<sub>2</sub> emissions at 1990 levels by the year 2000. In addition, there is an ongoing examination of policy instruments available to assist New Zealand reduce CO<sub>2</sub> emissions.

Outcomes of these initiatives have included:

- removal of the import duty on wind turbine generators;
- dissemination of information on potential renewable energy sources and their applications, including information on their economic, social and environmental impacts;
- identification of strategic priorities for research activities relating to renewable energy as in the report *New and Emerging Renewable Energy Sources: Priorities for Future Research*, EECA 1996; and
- provision of a series of guidelines published by EECA for developers and local authorities to ease the planning consent process for new renewable energy developments.

In addition, the energy market reforms have created opportunities for new forms of energy supply by enabling energy users to generate their own electricity, and by providing suppliers with the option of generating power for their customers who are connected to the national grid. This opportunity has been followed up by power companies such as Wairarapa Electricity, EnergyDirect and CentralPower which are either already supplying electricity from their own wind farms or have sought resource consents to do so.

### 1.3 The Resource Management Act

The general purpose of the Resource Management Act 1991 (RMA) (to promote sustainable management of natural and physical resources) is potentially favourable towards the development of new renewable energy resources to meet community needs. However, some renewable energy projects may be incompatible with some of the environmental considerations set out in part 2 of the RMA. For example, the adverse effects associated with a particular wind farm or small scale hydro development may be seen as unacceptable in the interests of protecting an ecosystem or coastal resource.

Energy is included in section 2 of the Act as a “natural and physical resource” and falls into the definition of a “contaminant” when discharged into the environment in a way which changes the condition of the environment. The “efficient use and development” of energy, as well as other resources, is one of the matters that councils must have particular regard to under section 7 of the Act when exercising their statutory functions.

The Act requires regional and district councils to consult with their community to develop a regional policy statement and regional and district plans in order to provide for the sustainable management of natural and physical resources. The policy for managing environmental issues associated with energy development, flows on from regional policy statements into regional and district plans. Most regional councils have identified energy use, and therefore the development of energy related resources, as an issue to be addressed within their policy framework.

Regional policy statements can also include objectives and policies that may have the effect of restricting or limiting the opportunity to develop some new renewable energy resources. In theory, objectives and policies for protection of landscapes, rivers, or the coast can coexist with policies promoting renewable energy. The potential conflicts between these policies should be resolved in the Regional Policy Statement and, if not, may be subject to Planning Tribunal decisions in future.

The potential of a particular renewable energy resource varies from district to district and recognition of this will depend on the plans for each region. For example, a regional plan for the management of a particular river could indicate opportunities for hydro development by diversion, through its water allocation rules, and a district plan may provide standards for height of structures, sound levels, and utility power line routes which favour wind farm developments for each area.

Policies and plans must be carefully considered in terms of the relationship and the opportunities they offer for energy development. Decisions made under the RMA with regard to renewable energy developments often deal with relatively new developments and issues. It is important that potential developers participate in the development of plans to ensure their interests are recognised. These issues are covered further in the report *Guidelines for Renewable Energy Developments — Overview*, EECA, 1995.

In addition to the RMA, there may be other legislation that could impact on proposed renewable energy developments, such as the Building Act or Hazardous Substances legislation. Early contact with the local authority is crucial to scope out all possible issues.

## 1.4 Overview of New and Emerging Renewable Energy Technologies

### Introduction

This section has two objectives, the first being to provide a brief introduction to the technologies covered in this report. Each introduction is a short note on the basic nature of the resource and the conversion technologies that have been developed or are under investigation. Further information is available in the relevant sections of this report. The material below is organized under the same headings and in the same order as the information on new renewable technologies is presented.

The second objective is to provide a brief commentary on the contents of this report in the light of earlier work in New Zealand on renewable energy potentials, in particular the report published by the Ministry of Commerce in 1993 entitled *Renewable Energy Opportunities for New Zealand* (referred to as the 1993 report from here on). The focus of the commentary is on whether new technologies are identified in this latest report (referred to as the present report) and whether earlier estimates of the total national resource potential have been revised. This section ends with a short conclusion where the major changes are reiterated.

It should be noted (both for this ‘overview’ chapter and the report in general), that issues raised throughout the resource sections are largely indicative of the aspects surrounding each technology, which in turn are largely dependent on the individual project scale and location. Due to the vast amount of information available on renewable technologies, this report can only highlight the main issues raised by each technology and suggest further contacts where available. This report is therefore not a fully comprehensive and detailed study of all issues surrounding each technology. For example, ‘environmental aspects’ is one of the sub-headings in the structure of each section. While the main positive and negative environmental aspects of each technology can be listed, the impacts are so dependent on the site chosen that any listing will be indicative rather than inclusive of all possibilities.

With regard to the economic analyses for each technology, it is desirable that economic comparisons use the same interest rate although settling on a figure is a vexed issue. A figure between 7% and 10% is usually mooted for this purpose. Proponents of technologies like photovoltaics favour low rate. PV systems involve a high up front cost but provide a long period of benefits with few operating costs. While using a high discount rate may work against PV technology, this technology is rapidly changing and society may be better off if some marginal investments are put off for few years. For further information, refer to the discussion in the 1993 *Renewable Energy Opportunities for New Zealand* report.

### Solar thermal

This technology refers to the conversion of sunlight into moderate to high temperature heat energy, usually in the form of hot water, steam or another working fluid. This heat can be used to provide space heating and air conditioning, as well as hot water supplies. High temperature fluids can also be used for industrial processes. The 1993 report covered this topic under the heading of passive and active solar. It focused on hot water technologies, but an appendix was provided on high temperature technologies. The present report provides more detailed information on solar thermal technologies designed to produce hot water. It also provides a brief note on high temperature solar thermal technologies in the section on Other Solar Conversion Systems.

The solar water heating technologies covered include the conventional approach of water running through tubes attached to flat metal absorber sheets (some with special surface coatings to maximize energy gain) and flat plate collectors with a specially treated working fluid (e.g. water with antifreeze) which absorbs heat and transfers it to a separate hot water supply. Flat sheet “heat pipe” collectors which absorb and exchange heat to the water supply using phase change materials are described. A system with an evacuated tube surrounding a heat pipe is also described.

The 1993 report provided rough estimates of the cost of solar water heating and also developed a scenario for increased use of this technology. There does not appear to have been any major technological developments since 1993 that have significantly lowered costs. The rising cost of electricity is making solar water heating more viable, however. The present report revises the earlier solar heating uptake scenario. It points out that if, in future, half the sales of electric water heaters were displaced by solar heaters, then the annual savings would be 75 GWh per annum (pa) cumulative each year (i.e. 750 GWh pa at the end of 10 years). The 1993 report noted that there was insufficient data to estimate the potential of solar water heating for industrial and commercial building applications. This situation has not changed.

### ***Passive solar in buildings***

Passive solar technology is taken to mean the use of architectural features to collect, store and distribute space heat and also to facilitate daylighting; the penetration of sunlight into a building to reduce the need for artificial lighting. Space heat management through effective ventilation and conservation (e.g. building insulation) is also an integral part of passive solar design. A distinction is often drawn between active and passive solar technologies with the former relatively more reliant on the use of pumps and fans to transfer energy, or other devices to convert it to another form for subsequent use.

The present report provides an overview of passive solar space heating and also presents information on daylighting technologies not covered in the 1993 report. It emphasises the cost effective nature of many passive solar architectural features when applied to existing as well as new houses. The potential energy savings from effective daylighting of commercial buildings is also highlighted. Examples of successful passive solar domestic and commercial buildings are noted. The relationship between passive solar design and energy conservation through insulation, double glazing etc. receives more attention than in the 1993 report.

The 1993 report identified an indicative energy saving of 2000 kWh/yr for each new home built to passive solar design principles. With around 20,000 new homes built each year, this translates into an annual savings of approximately 40 GWh pa or 400 GWh pa at the end of 10 years. The present report does not revise these figures.

### ***Photovoltaic technologies***

Sunlight can be directly converted to electricity via the photovoltaic effect which occurs in certain semiconductor materials. The information on photovoltaic (PV) technologies in the present report is far more comprehensive than that presented in the 1993 report. PV technology is rapidly improving, costs are coming down and cost effective applications have already been established in consumer products (e.g. calculators), remote industrial sites (e.g. cathodic protection), RAPS schemes and, in special cases, distributed and embedded power supply.

The present report describes the key features and trade-offs of the main PV technologies. The key trade-offs are the cost of manufacturing cells, the ease of incorporating cells into different module shapes, and module conversion efficiencies.

Amorphous silicon (a-Si) cells are relatively cheap to manufacture and can be produced as light, thin and flexible panels suitable for incorporation onto roofing tiles, windows, etc. Cell conversion efficiencies are relatively low (10% to 12% in the laboratory) but research is under way to improve this via such means as production of multi-junction devices. A moderate improvement in efficiency combined with the low cost of a-Si cells could make this a very competitive electricity generation technology within ten years.

Single crystal silicon (c-Si) cell technology, which has been developed on the back of the micro-electronics chip industry, represents the other end of the spectrum. This technology tends to be expensive but has the potential for relatively high conversion efficiencies (perhaps 20% for commercial modules by the year 2005). Adoption of less stringent quality standards more suited to PV requirements together with technical improvements could also see costs lowered substantially.

The other two main silicon technologies, namely multicrystalline and polycrystalline cells tend to be slightly less efficient than c-Si cells but cheaper to manufacture. Another silicon based technology with considerable promise is multi-layer silicon, under investigation at the University of New South Wales, but this is still at the

laboratory stage. A variety of non silicon semiconductors are also being investigated and their development has advanced to manufacturing trials. Examples include copper indium diselenide and cadmium telluride. These materials offer relatively high efficiencies, ease of manufacture and longevity.

The present report provides substantially more detailed information on energy supply costs from PV technology than the 1993 report. The 1993 report indicated that PV technology might be competitive with other forms of grid power by the year 2010. The present report is slightly more optimistic and advances the point of competition to the year 2005. The interesting question is not whether PV technology will become competitive, or when, but rather which of the range of technologies under development will first become widely used for distributed, or utility power generation.

The potential electricity resource from PV use is vast. The present report updates the single household potential presented in the 1993 report. A large house with an annual power demand of 15,000 kWh could obtain all its power from 100 m<sup>2</sup> of PV modules on the roof and a suitable energy storage facility.

### ***Other solar conversion systems***

Under this heading the present report covers high temperature solar thermal applications, it mentions ocean thermal energy conversion (an indirect solar energy source) and provides an introduction to photoelectric chemical conversion. Ocean thermal conversion was not covered in the 1993 report because it was considered to be an embryonic technology with limited potential to New Zealand; it appeared to be best suited to places where there is deep water close to shore with a marked temperature differential between surface and bottom temperatures.

Photoelectric chemical conversion, not mentioned in the 1993 report, is a special form of PV technology using liquid junction cells. These cells consist of a semi conductor coated with dye which in turn is in contact with an electrolyte. Suitable dyes include metal polypyridyl complexes and porphyrins. Porphyrins occur in nature and are used to transport oxygen in blood, collecting sunlight in chlorophyll and other tasks. Research in New Zealand is aimed at developing synthetic porphyrins that will facilitate artificial photosynthesis.

### ***Woody biomass***

Woody biomass covers materials such as waste material derived from forest operations such as thinning and harvesting, wood processing residues, timber salvaged for firewood, and purpose grown fuelwood plantations. The earlier 1993 report also treated cereal straw and stover as part of the biomass resource. Woody biomass can be converted via various pathways into a range of solid, liquid and gaseous fuels which in turn can be used in different plants to produce heat, electricity, and motive power. The production of woody biomass and its conversion into useful energy are dealt with in two different sections of the present report.

Earlier estimates of the future availability of woody biomass have been updated using new information. A distinction is drawn between technical potential and usable potential, the latter allowing for environmental, technical, commercial and other constraints. In total it is now thought that the total usable resource by the year 2000 will be around 38 PJ. This is less than the 1993 estimate even after allowing for the omission of straw materials and a different time frame (year 2002 in the 1993 report instead of year 2000).

The main changes in the resource figures are a 25% drop (approximately) in the estimate of usable forest arisings, a marked increase in the estimate for processing residue availability (up 270%) and an almost nil entry for energy plantation. The energy plantation figure in the 1993 report was based on a technically feasible scenario. The present report notes potential land use competition, demand for wood as a fibre rather than energy source, and lack of infrastructure in New Zealand when arriving at a low estimate of likely fuelwood plantation development.

The present report also revises the cost estimates for woody biomass, except that from energy plantations where the 1993 figures were only adjusted for inflation. With the better information now available, the procurement of woody biomass is considered generally slightly more expensive than in 1993. The cost ranges are still fairly wide reflecting the range of different circumstances for this material.

### ***Agricultural biomass crops***

The 1993 report dealt with purpose grown agricultural energy crops only in the context of biogas technologies



and in a two page annex on liquid fuels. At that time crops such as oats, kale, high growth rate grasses and sugar beet were envisaged. The present report provides more information on energy cropping issues, trends, and potential than the earlier report. Criteria for the selection of suitable energy cropping plant species are identified. The report notes a nascent convergence between farming and forestry and this is reflected in the identification of eucalypts and broom as suitable plants. Other species considered to have the desirable characteristics include sweet sorghum and various canes and bamboos.

The energy cropping potential in New Zealand is huge. The present report notes that over 5,000,000 ha of suitable land could become available without disturbing substantially current food production. The 1993 report indicated that using biogas conversion each 10,000 ha of energy crops could produce 100 GWh pa. Consequently 5 million ha equates to 50,000 GWh pa. Instead of providing an annual electricity yield, the present report provides a power output, namely 8000 MWe, which converts to 70,000 GWh pa.

The latest material highlights the potential profitability of energy biomass production to farmers. The estimated cost of biomass energy, at \$0.60 to \$1.60 per GJ, is significantly lower than those presented in the 1993 report; \$5/GJ based on a kale crop, and \$2.50 to \$5.00 for short rotation Eucalyptus. The present report notes that the latest cost estimates cannot be directly compared with previous local or overseas figures because they rest on a significantly different approach and set of technologies. For example, new crops and conversion systems open up the possibility of producing valuable chemical and material co-products as well as fuels or power, thereby sharing procurement cost across several outputs.

### ***Municipal solid wastes***

The conventional approach to disposal of municipal solid wastes (MSW) has been either landfill, with the possibility of methane gas collection, or incineration with or without energy recovery. Increasingly MSW management involves a degree of waste separation so that certain fractions (e.g. waste paper) can be recovered for further use. Under the section on wet biomass the present report looks at another energy strategy, namely passing MSW through digestors to directly produce biogas (which was touched on in the 1993 report).

The MSW section of the present report takes a radical departure from previous strategies. Although it covers incineration and the production of refuse derived fuels (RDF), the focus is now on the extraction of useful materials, chemicals etc., as well as energy from MSW, while minimizing the degree of prior waste separation.

Gasification and cracking processes to produce gases and oil substitutes, or monomers are outlined. In all cases the aim is to crack polymers in the MSW down to some simpler molecular component. The major difference between the process is the degree of cracking and consequently the nature of the products, but there are also differences in economies of scale, cost effectiveness etc.

The processes that produce monomers can market a raw material with many potential uses. Four such processes are described; the BASF approach, the Battelle approach and the BP approach all of which treat mixed plastics; and the Convertech approach (being pioneered in New Zealand), which can deal with a variety of feedstocks. While the Convertech process was not initially designed to handle mixed waste, it has potential to treat MSW to produce a cleaner burning RDF waste and valuable by-products. None of the above monomer recovery processes were mentioned in the 1993 report.

### ***Dry biomass conversion***

Dry biomass is taken to mean above ground terrestrial plant components with relatively low moisture contents suitable for direct burning. In practice this mean woody biomass and dry agricultural residues like straw. The present report provides more detail on conversion technologies for dry biomass than the comparable section in the 1993 report.

The simple combustion of wood is a well established technology. The report covers various conventional combustion plant as well as emerging technologies, such as fluidized bed combustion, and the use of pulverized wood as feedstock for a gas turbine. Various ways to gasify dry biomass, are also covered. The use of pyrolysis to break down biomass and produce a range of liquid fuels and gases is outlined. The report also mentions low temperature conversion processes such as steam explosion, acid hydrolysis and solvolysis to produce liquid fuels, sugars and various chemicals.

The economics of various conversion technologies are examined. The well established power generation processes yield electricity at around 15 c/kwh given a feedstock price of \$5/GJ. This figure is similar to that presented in the 1993 report.

### ***Conversion of wet biomass***

Biomass with a high moisture content, such as freshly harvested agricultural crops, can be converted via various means to produce liquid and gaseous fuels. The 1993 report focused on anaerobic digestion to produce biogas. It also provided a short appendix on producing liquid fuels from biomass. The present report covers biogas production and provides more information on fermentation, production of plant and animal oil derivatives and other means of producing liquid fuels, than the earlier report.

The 1993 report provided a first order guesstimate of 400 GWh for the amount of electricity that could be produced via the production of biogas from on-farm animal effluents, on-farm crop residues and food processing wastes. The present report has revised the data for these waste sources and indicated that the maximum potential is nearly 1400 GWh. Practicalities of collecting and using the waste resource would mean that the usable potential would be somewhat lower.

Biogas can also be obtained from municipal refuse by controlled digestion or by tapping landfill gas. New Zealand experience with landfill gas collection schemes has grown since 1993. The 1993 report provided a separate chapter on landfill gas and estimated that the usable resource by the year 2000 could be 150 GWh. This figure has not been updated, but the present report does record that the total potential of all refuse, if passed through digestors rather than placed in landfills, is around 680 GWh. Present information on the production of biogas via digestion of purpose grown crops is little different from that reported earlier.

Liquid fuels from biomass is an area that may warrant further attention in future. New Zealand's tallow production, for example, if converted to esters could displace 10% of the national diesel demand. New Zealand has experience in the production of alcohol by fermentation of whey, a by-product of the dairy industry. Even with an expanding dairy industry the energy quantities likely to be available are small. Growing purpose crops suitable for fermentation is an option, but little research has been done on this subject since the conclusion of earlier studies by the NZERDC during the 1980s.

### ***Small hydro power***

Small hydro is taken to mean development of power schemes of 1 to 10 MW capacity. The 1993 report contained a short appendix which provided an estimate of the total additional generation potential of schemes of this size. The present report provides a slightly lower estimate, namely 930 MW or 3,882 GWh pa, than the 1993 report. The 1993 estimates of the amount of energy that could be generated within different cost bands (e.g. 5 to 10c/kWh) has been revised in the present report. It is now thought that there is less power available at a moderate cost (i.e. less than 10 c/kWh) than earlier estimates.

The present report provides information on technological developments, environmental, social and other aspects of small hydro not covered in the 1993 report. Technological developments include innovative techniques for civil works and related new materials. A wide range of turbo-generator systems and controls is also available now, and this increases the likelihood that a cost effective package is available to suit a particular circumstance.

Mini-hydro systems, that is schemes with capacities of 1 MW are covered in the current report. Smaller micro-hydro schemes, usually installed to supply power to a single consumer, such as a remote tourist venture, also omitted from the 1993 report are covered in the present report. It is not practical to provide an estimate of the total mini and micro hydro capacity in New Zealand, but it would be much less than that from small hydro schemes. Nonetheless mini and micro hydro can make a valuable energy supply contribution to individual consumers or parts of a distribution network.

### ***Wave, tidal and ocean current power***

Tidal power harnesses the regular rise and fall of the tides. In suitable bays or estuaries impoundments are created to enable the water from high tide to be released through turbines or magneto-hydrodynamic generators to produce power. It has also been proposed that ocean waves running up a ramp could be used



to increase the amount of water available for generation at high tide. At present tidal power technology has not advanced beyond the demonstration stage. Cost effective tidal power sites are likely to have a high tidal range (approximately 5 metres) and the potential to impound large volumes. Lack of suitable sites in New Zealand and the embryonic state of the technology meant that tidal power was not covered in the 1993 report.

In principle ocean currents, especially tidal streams, could be used to generate power. Several projects have demonstrated the technical feasibility of using various types of underwater turbines to produce power from ocean currents. In New Zealand several tidal narrows, such as Tory Channel in the Marlborough Sounds, may be suitable as ocean current power sites. More information is needed on the characteristics of potential sites together with further technology development before ocean current power is likely to be applicable to New Zealand. Ocean current power was treated as a subset of tidal power and not covered in the 1993 report.

The energy in waves can be converted to power while the waves are travelling off-shore or when they strike land. Various mechanical systems have been trialed to capture, concentrate and convert wave energy. A simple system to conceive is waves running into the base of a vertical cylinder moored offshore or built into cliffs adjacent deep water. The rise and fall of the waves creates a blow hole effect where the compressed air produced is used to drive a turbine.

The 1993 report emphasised that New Zealand has a vast wave power potential but that further development of technologies was needed to lower costs and increase reliability. The present report has been able to identify the most promising stretches adjacent to the New Zealand coast for wave power. It also reports on a new technology being considered for wave power, namely piezoelectric materials. These generate electrical currents when flexed, pulled or otherwise stressed. Cables between buoys and anchors, or floating blankets of these materials may be able to generate electricity from wave motion.

### ***Wind power***

The wind power chapter of the present report focuses on large wind turbine generators (greater than 200 kW) that are connected to a utility network and are installed on land rather than off-shore. Small wind turbines are mentioned in section 6, which covers remote area schemes. Since the 1993 report significant progress has been made towards the application of wind power technologies. A small wind farm was commissioned in the Wairarapa in June 1996. Resource consents have been granted for a large wind farm at the northern end of the Tararua Ranges. An appeal has been lodged against the refusal of consents for a major wind farm proposed at Baring Head near Wellington.

The present report confirms the 1993 estimate of the total amount of wind power likely to be available from the main potential wind farm sites in New Zealand, namely approximately 12,500 GWh pa. It updates and extends the earlier material on the cost of wind power. Present thinking is that the best sites in New Zealand can generate electricity for around 7 c/kWh including transmission costs.

Wind power is a mature technology, but further development is occurring to increase power output and reduce fatigue loadings (e.g. variable speed rotors and power electronics), simplify turbine mechanics (direct drive rather than through a gearbox), and improve robustness (specially designed stalling airfoils). Experience to date favours two or three bladed horizontal axis machines placed on tall lattice or tubular freestanding towers. Radical alternatives are still suggested from time to time, the latest being a small diameter turbine placed upwind of a large cowl or air scoop designed to concentrate airflow. Such alternatives have not yet been shown to be competitive with conventional technology.

### ***Integrated energy systems***

This section, not included in the 1993 report, provides a discussion of how renewable energy technologies can be practically integrated with traditional energy supplies. Examples include co-firing of coal and woody biomass and the combination of wind and hydro power generation. It discusses the different approaches needed to provide power to the national grid versus embedded generation and distributed generation, down to small and isolated local power supply systems. Hybrid systems using a combination of the individual renewable energy technologies, possibly in association with conventional backup systems such as diesel generating sets, are also discussed. On a small scale, remote area power supply systems (RAPS) are expensive, but often competitive with extending the local electricity distribution network.

Energy storage systems and the potential for hydrogen fuel are also included.

### **Conclusions**

Compared with the 1993 report, two areas of technological innovation particularly stand out. The first is the substantial research and development effort into PV and related liquid junction cell technologies. It is very likely that this R&D will result in a future large uptake of PV technologies, but only just beginning within 10 years. The scale flexibility of PV systems means that they will find beneficial applications at all levels in electricity supply systems, from distributed generation through to major utility installations.

The other noteworthy area of technological innovation is in the conversion of purpose grown crops and waste material such as MSW to chemicals and other raw materials. Technologies under development promise a strong synergy between waste management, recycling and energy production. They may also open up commercial energy cropping or forestry opportunities for New Zealand farmers. A recent estimate of the land area available for agricultural biomass crops is now available. At over five million hectares, the energy potential from this land is enormous; over 50,000 GWh pa of electricity could be generated from the biomass harvest.

Another major change from 1993 is the progress that has been made since then on adopting wind power technologies and developing local resource assessment and project management skills.

In terms of estimates of national resource potentials, the main change is in the area of woody biomass. The estimate for woody biomass has been reduced, largely because only steady progress on fuelwood plantations is now expected. Recent survey work has also enabled the estimate of the usable forest arisings resource to be refined and the result is a figure 25% lower than previously thought. It should be noted that the future for fuelwood plantations could be brighter if new conversion processes, such as the wood gasification Converttech system, establish themselves.

## **1.5 Future Policy Options**

### **Influencing factors**

A considerable range of new and emerging renewable energy developments in New Zealand are now under evaluation, with a significant number of projects either already under way or likely to proceed.

However, some energy commentators argue that a faster rate of uptake of such developments is desirable for a variety of reasons including:

- meeting New Zealand's international obligations to reduce carbon dioxide emissions;
- improving the sustainability of the nation's future energy supplies; and
- helping the transition to the energy supply mix needed for ongoing economic development following the impending depletion of the Maui gas field.

Also, arguments are advanced that there are factors which may be impeding the adoption of renewable energy developments to the optimum level desired by society. These arguments include the following:

- Significant external costs of fossil fuel production, distribution and use are not currently included in fossil fuel prices. Thus renewable energy supply options have to compete with fossil fuelled alternatives which are too cheap, and New Zealand as a whole is worse off due to the impacts of these fossil fuel related "pollution costs".
- At present, avoidable transmission costs are under consideration as part of evolving transmission pricing regimes. The results of these deliberations may influence the economic viability of new small electricity generation plants (using renewable energy or fossil fuels), the location of which enables them to supply electricity direct to consumers, thus avoiding use of the Trans Power national electricity grid.
- Where renewable energy technologies (e.g. wind, solar and wave power) can only provide power intermittently or where supply is otherwise dependent on unpredictable weather conditions (e.g. small

hydro), a back up electricity supply will be required. There may be extra costs associated with maintaining this back up supply. Similarly, for remote area power systems, the intermittent nature of some renewable resources (e.g. solar or wind) may require a back up energy supply reducing the economic viability of the system.

- The Resource Management Act as currently formulated and/or interpreted may not readily facilitate Local Authorities administering resource consents to balance any national benefits from the greater use of renewable energy on the one hand, and local environmental effects on the other.
- The renewable energy resources of New Zealand tend to be poorly documented as well as poorly understood by the general public compared with the traditional fossil fuel alternatives. In addition, there is a lack of experience and local application of some technologies. As more information is gathered on the renewable energy resource and technologies to capture it, this needs to be disseminated to decision makers, investors and the general public.

### ***Policy options***

A number of potential policy responses could help overcome these perceived barriers to the appropriate uptake of new and emerging renewables in New Zealand, including:

- environmental costs becoming fully reflected in fossil fuel energy prices by mechanisms such as carbon taxes and/or tradeable emission permits or obligations;
- the formulation of national policy statements on energy and/or carbon dioxide emissions;
- enhanced information activities and demonstration projects for renewables to increase public awareness;
- ensuring that depreciation rates for new and emerging renewable developments are set at appropriate levels;
- enhanced funding for renewable energy resource proving and analysis;
- enhanced support for renewable industry training, education and industry facilitation;
- targeted assistance for the development, demonstration and commercialisation of key new renewable technologies, perhaps using the ERDC (Energy Research and Development Corporation) model from Australia;
- encouragement of “green pricing” and “green investment” developments; and
- contestable and carefully targeted financial incentives (perhaps funded by revenue gained from carbon taxes ) to encourage the early adoption of key new and emerging renewable energy technologies, perhaps modelled on the United Kingdom’s NFFO (Non-Fossil Fuel Obligations).

These, and other potential policy options all have advantages and disadvantages and need to be analysed with care to ensure that, if implemented, perverse effects and market distortions are minimised. They are likely to be debated extensively in the future, especially as the results of the newly deregulated and competitive energy markets emerge, as New Zealand’s climate change response strategy unfolds and as the post- Maui gas energy future approaches.

The adoption of any of these, or other policy options have the potential to greatly enhance the likely new and emerging renewable uptake rates suggested in this report. Therefore ongoing debate and analysis of these policy issues is critical for the development and uptake of renewable energy in New Zealand.



## 2 *Solar Energy*

It is appropriate that this section appears first in the report as the “solar engine” is also directly or indirectly responsible for the other renewable technologies considered later, namely biomass, wind, hydro and wave (together with tidal power which results from the gravitational pull of the moon).

This section on solar energy first examines the solar resource, evaluates the potential for solar thermal energy, then considers passive solar inputs to buildings. Power generation from photovoltaics and high temperature thermal systems are then discussed followed by a brief look at the potential for new photo-conversion systems.

It is evident that a holistic approach is required if appropriate solar technologies and philosophies are to be recognised and implemented. This report attempts to provide such an approach.

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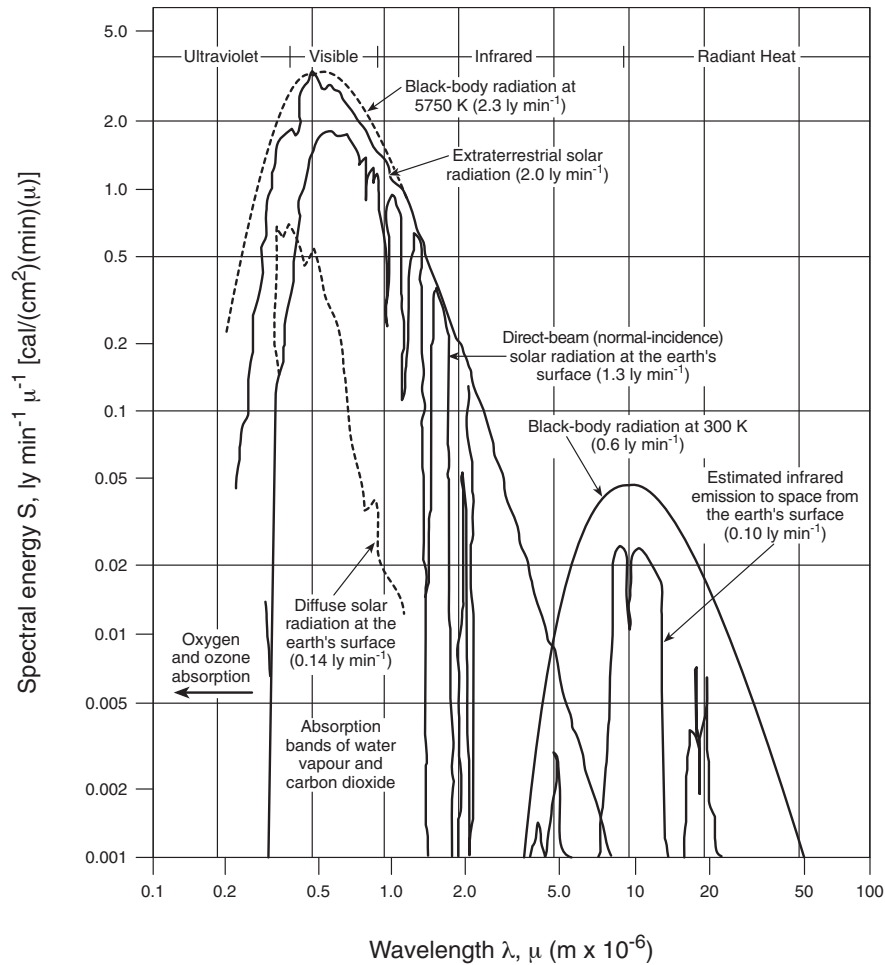


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## 2.1 The Solar Energy Resource

Energy from the sun arrives at the earth's outer surface in the form of a beam of radiation with a wavelength distribution closely approximating that from a perfect radiator, a "black body", at 5750 K (degrees Kelvin; 273 K = 0°C). It is slightly modified by absorption of some specific wavelengths by components of the atmosphere before it reaches the earth's surface, where it is absorbed, irreversibly degraded to a lower temperature, and then re-radiated into space. A simple calculation treating the earth as a rotating sphere leads to an expectation of an equilibrium surface temperature of about 250 K, or -23°C.

This expectation is quite close to the actual mean surface temperature of the earth and if one takes into account the "greenhouse effect" of the atmosphere then the expected temperature is higher and closer to the actual temperature. The character of the incoming and outgoing radiation is illustrated in Figure 2.1.



**Figure 2.1: Solar and earth temperature spectrum (1 ly min<sup>-1</sup> = 1 langley/minute = 698 W/m<sup>2</sup>)**

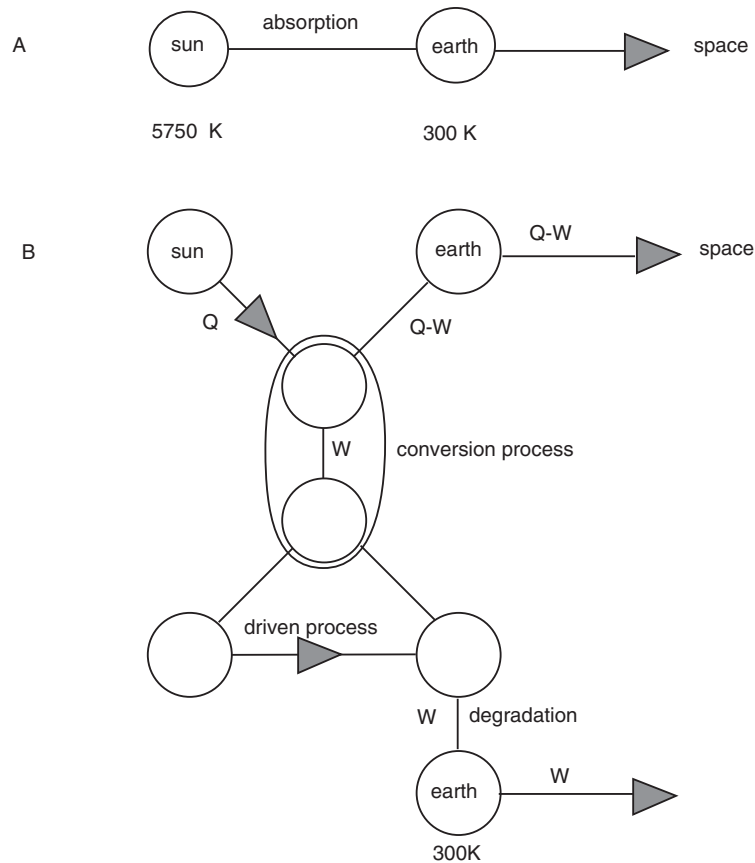
In thermodynamic terms the maximum convertibility of an amount of thermal energy  $Q$  to mechanical work  $w$  is related to the initial and final temperatures  $T_1$  and  $T_2$  by the expression:

$$W = Q(T_1 - T_2)/T_1$$

With a source temperature ( $T_1$ ) of 5750 K (solar input) and a sink temperature ( $T_2$ ) of 300 K (earth's surface), this gives a convertibility of around 95% and implies that in its passage from solar temperature to earth temperature the radiation is capable of being used as a source of mechanical work with high efficiency, so long as a mechanism can be found for converting photon energy to another desired form of energy.

Since the ultimate fate of almost all earthly energy use is its degradation to thermal energy at earth's surface

temperature, this in turn implies that solar energy use is also environmentally benign. In essence, all that we have done in “using” solar energy is to create conditions such that its degradation from 5750 K to 300 K has occurred less irreversibly than it would have under “natural” circumstances. This is illustrated in Figure 2.2, which compares the paths for direct absorption (path A) and usefully applied (path B) solar energy. The key to using solar energy is to devise a mechanism (the conversion process) that will enable us to do something that would not happen of its own accord (the driven process). In the long run, however, all the energy input,  $Q$ , will finish up being re-radiated to space.



**Figure 2.2: Generalised solar engine**

The exception is when solar energy is used to bring about a chemical reaction, the products of which are permanently stored. This is in fact what has happened in the case of fossil fuel formation where a small part of the energy used for photosynthesis in times past has been stored as coal, oil and gas. An even smaller amount is stored in the plant and animal biota on both the land and in the oceans.

## Magnitude

The annual energy flux passing from the sun to the earth's surface and being re-radiated into space is approximately  $10^{17}$  W, which is 10,000 times the  $10^{13}$  W presently consumed by humanity. Taken in conjunction with the thermodynamic argument above, this in turn means that solar energy is, in principle, easily capable of serving all humanity's needs as long as we can collect and “use” it with an overall efficiency exceeding 0.01%.

## Intensity

The intensity is often said to be not very high at  $1000 \text{ W/m}^2$ . However, even this is quite good when compared with other renewable sources on a ground cover basis. For example, the area covered by Lake Dunstan (Clyde

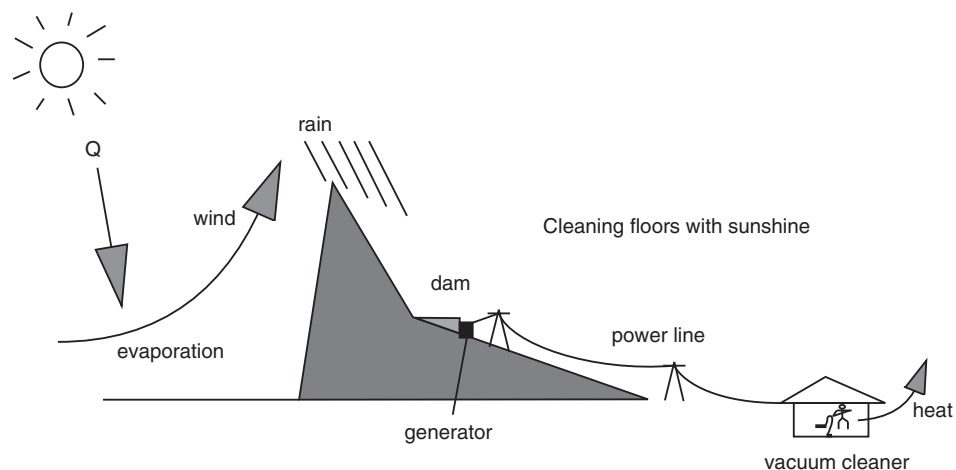
dam) is  $25 \text{ km}^2$  for a unit that generates about  $2 \times 10^9 \text{ kWh/yr}$ . The amount of solar energy falling on that same area is about  $4 \times 10^{10} \text{ kWh/yr}$  and if converted to electricity at present day photovoltaic efficiency (10%) would yield about twice the output of the Clyde dam. The capital cost of the collectors would, however, be at present day prices about 8 to 10 times that of the Clyde dam.

In biomass terms, dry matter is accumulated in *Pinus radiata* forests at the rate of about 8 dry tonnes per year per hectare, giving a net efficiency of energy fixation of about 0.02%. Faster growing plant species can accumulate more than three times as much dry matter, giving a net efficiency of energy fixation of closer to 0.06%.

## Storage

We are not usually concerned with energy itself so much as with the various functions and services that require an energy input, such as keeping warm, moving vehicles and powering the many machines and appliances we use. The usefulness of any energy form lies in our ability to collect and store it for use as required and our ability to later convert it to a particular function.

It is not possible with present day technology to store photons or electrons directly in large amounts. We must therefore convert the solar energy into some storable form. To achieve this one needs collection, concentration, and storage methods and also methods of conversion of one energy form to another. Of particular concern are the stability of the stored forms and the efficiency of the conversion methods. This can be illustrated (Figure 2.3) by a brief consideration of the relatively indirect use of sunlight to vacuum clean a floor through the medium of hydroelectricity. In New Zealand, this is achieved by firstly evaporating water from the Tasman sea. This is then carried by the wind to high altitudes, where it condenses and falls as rain over a large area. The fallen rain on the land is concentrated into rivers and stored in dams. From the dams, it falls under gravity through hydro turbines, which in turn rotate the generators, producing the electric current. This is transported into the house, where it rotates the motor driving the fan in the vacuum cleaner creating the air flow, which picks up the dirt off the floor. In order to provide a useful service, the original solar photons have undergone about 15 energy transformations!



**Figure 2.3: Solar vacuum cleaner**

The overall efficiency of this process is about 0.003%. Nevertheless because of the large areas of natural collectors (ocean, catchment areas and valleys) and the ease with which we can build concentrators and storage devices (dams), it is still a useful method of conversion of sunshine into clean floors.

One of the characteristics of many renewable energy sources (e.g. sun, wind, wave, tide) that is different from the fixed sources (fossil fuels) is their intermittent nature. Coal and oil, however, do not come and go in unpredictable ways. Once formed, they tend to stay put until we discover them and decide to “use” them. The fossil fuels have, as it were, already concentrated the radiation and turned it into storable forms. Indeed that

is the very basis of their existence. Solar energy converted to biomass has a moderate storage life based on the life of the plant and the time it takes to decay after dying. Solar energy converted to evaporated water has a short life as stored water at some elevation from which its gravitational potential energy can be converted to electricity. Solar energy absorbed into a black surface has a very short storage life before being re-radiated into space. The usefulness of a solar conversion method often depends on the particular form in which the energy is required and its storeability. Hot water is used on a day-to-day basis and can be stored locally in convenient quantities for domestic use. This in turn makes the use of solar energy for augmenting the energy input to domestic water heating relatively attractive on a household scale. By comparison, the storage of photovoltaic generated (low voltage) electricity in chemical form in a battery and its conversion to higher voltage alternating current to drive machines are neither simple nor cheap. Therefore, photovoltaic electricity has as yet achieved only relatively low levels of implementation in special applications such as communications, lighting and in remote areas for communications and power generation where “mains” power is not readily available (see section 2.4).

## ***End Uses***

The end uses of solar energy can be in the form of:

- “raw” radiation such as daylight used for lighting;
- processes driven by electricity derived from a photoelectric cell in which the energy of the photons is converted to electronic energy;
- chemical energy from a process that converts the photon energy to chemical potential energy as in photosynthesis, which occurs in plants to produce carbohydrates and cellulose; or
- thermal energy in a collector in which the energy of the photons is used to raise the temperature of the absorbing material.

## ***Conversion Processes***

The primary conversion devices for solar direct collection of solar energy are related to the end use and can be classified as follows:

- low temperature thermal, including passive solar building design;
- high temperature thermal;
- photovoltaic; and
- photochemical.

The indirect methods that will be discussed in other sections include hydro electricity, wind power and wave power.

## 2.2 Solar Thermal

The maximum intensity of sunlight in New Zealand is about  $1000 \text{ W/m}^2$  and the number of sunshine hours ranges from about 1600 in Invercargill to about 2450 in Blenheim with around 2000 h/y in the main centres of population. The energy falling on a horizontal surface ranges from about  $25 \text{ MJ/m}^2/\text{day}$  in summer to about  $5 \text{ MJ/m}^2/\text{day}$  in winter. The distribution of sunshine hours in NZ is shown in Figure 2.4.

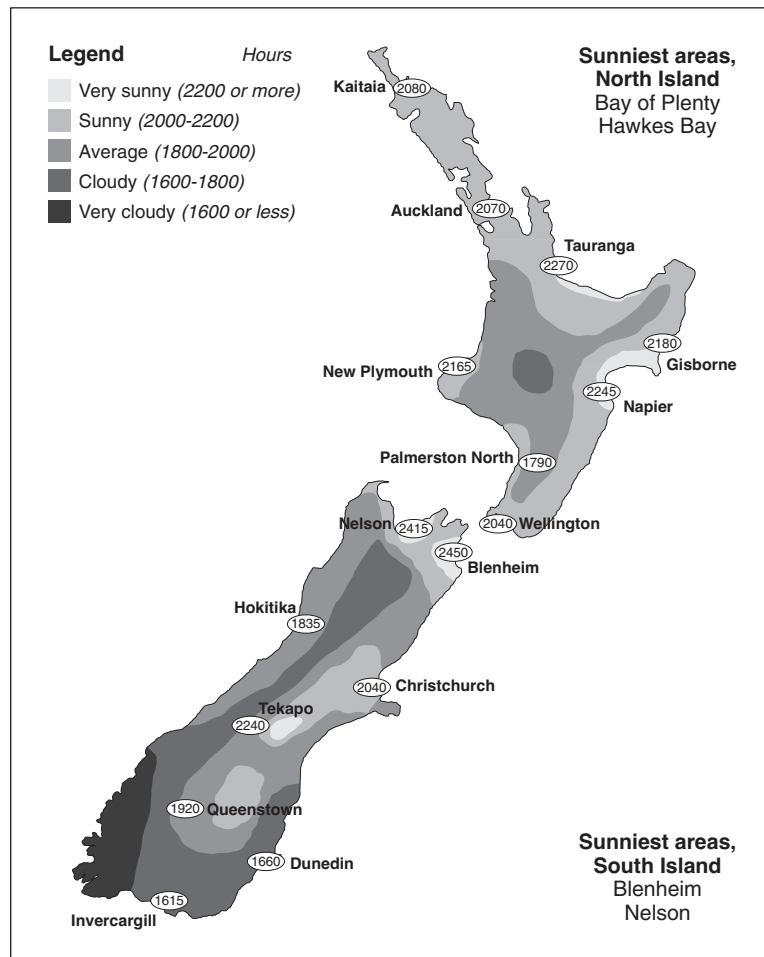


Figure 2.4: Sunshine hours

Therefore, the amount of sunshine falling on the roof of a typical NZ house in a year is almost 200,000 kWh or about 20 times the total electricity usage. There is, therefore, more than enough to meet all the household needs. The main challenge is how to collect that energy, given that both the source and the use are intermittent and follow different patterns.

The main uses of low temperature solar thermal energy are in space heating and water heating, especially domestic water heating.

Space heating is usually achieved as passive heating in which natural sunshine is trapped as thermal energy in an absorbing material that is part of the structure, as in Figure 2.5. This is discussed in detail in Section 2.3.

Solar water heating uses the sun's energy to heat water directly. This is a technically simple process that is usually considered environmentally benign in that it uses readily available materials and imposes no direct load on any other energy source or on the environment. The other advantage is that it reduces electricity or other water heating fuel costs. The main disadvantages are that it is dependent on an intermittent source of energy and like many other demand-side conservation and management measures, it requires capital outlay on the part of the user. In commercial terms, investment often involves a lengthy pay-back period.

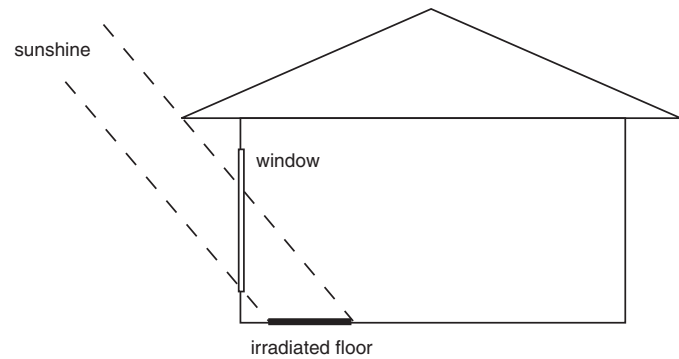


Figure 2.5: Passive heating

The amount of energy used in a typical New Zealand household was estimated in 1991 to be around 11,000 kWh per year; this estimate has not been verified more recently. It is possible that with the increasing use of washing machines for both clothes and dishes and the rising expectations of hot water availability (as evidenced by the use of larger hot water cylinders) the current national average is now higher than this. Based on domestic use being 40% of total electricity use, this would make individual household use close to 10,000-12,000 kWh per year, of which hot water would be 3700-4000 kWh. Another estimate could be based on the assertion that each person consumes about 40-50 litres of hot water per day. This would put domestic hot water use at about 3000 kWh per household per year. The extent to which these various estimates are independent is not known and a more accurate indication of domestic energy use will clarify these estimates.

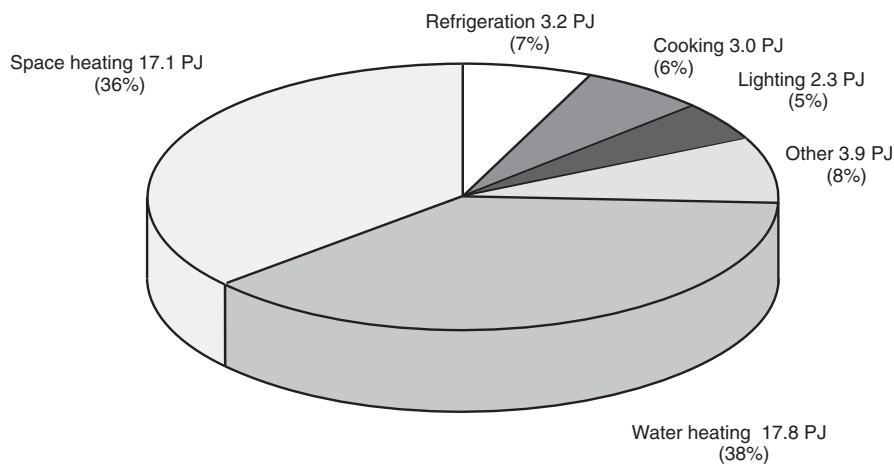


Figure 2.6: Domestic sector energy uses (EECA Energy Use Database, 1992)

Solar heating for swimming pools usually uses simpler and less expensive equipment than that for domestic water heating. This is fortunate because the major losses from pools are due to evaporation and to make up for these losses would require a pool heating collector with an area equal to at least half of that of the pool. Other opportunities for the use of solar water heating in commercial and industrial applications are yet to be developed. The remainder of this section will be concentrated on domestic water heating.

### 2.2.1 Technology Review

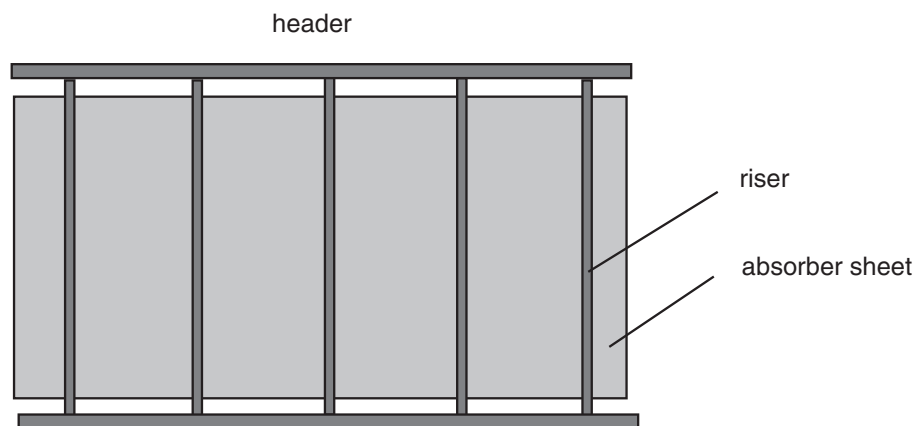
#### Solar collectors

The amount and temperature of hot water in a store will depend on the size of the store, the area of the collector, the pattern of water use and the immediate water use. The use pattern and the sunshine pattern do not coincide so it becomes necessary to use some averaging process. The use pattern is generally more constant than the supply pattern (water is used every day but the sun sometimes does not shine for several days at a time).

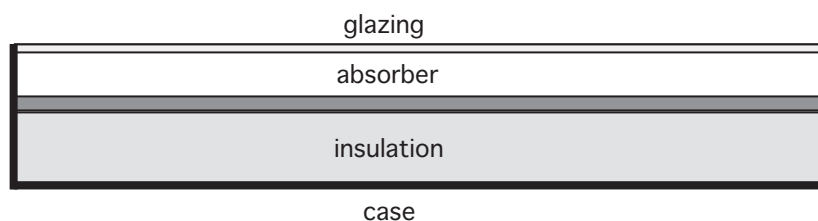


Therefore, it is necessary to provide an alternative energy supply and to design the collector system to provide some fraction of the total annual energy requirement rather than the actual daily requirement. The percentage decided on is dependent on the storage one wishes to provide and the area of collector one wishes to install. In New Zealand the rule of thumb is to aim for about 50% to 75% of the annual energy requirement.

Solar water heaters almost invariably operate by absorbing solar energy on a blackened surface and then conducting the derived heat to a water flow and hence to a storage cylinder. The absorber is usually in the form of a flat plate with attached water tubes running between a supply and a delivery header, as shown in Figure 2.7. The absorber unit is usually placed in a weatherproof case with insulation behind the absorber and a transparent cover in front as shown in Figure 2.8.



**Figure 2.7: Tube-on-sheet absorber**



**Figure 2.8: Flat plate collector**

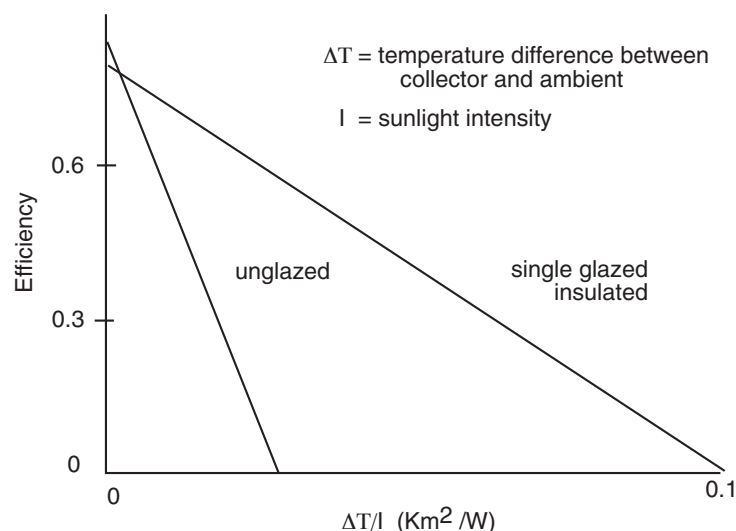
The efficiency of a flat plate tube-on-sheet collector depends on:

- the intensity of the solar radiation;
- the operating temperature of the panel; and
- the general construction of the panel, including such things as the transmission of the cover, the absorptivity of the sheet, and the quality of the insulation.

There are various compromises made in these factors but in general the overall performances of commercially available flat plate collectors are fairly similar and can be described by the Hottel-Whillier-Bliss (HWB) relation (Figure 2.9). The maximum efficiency of conversion of solar energy to hot water is about 72%. As the water temperature rises, the efficiency falls so that at a water temperature of around 60°C in bright sunshine, the efficiency is around 45%.

The overall daily effectiveness is usually about 30% to 40% of the total solar energy input. However one must be aware that this varies enormously according to the way in which the system is set up and from day to day.

As can be seen from the HWB plot, when the system is operating only a few degrees above ambient, as is the case of swimming pool heating, then poor insulation and lack of glazing are not serious disadvantages.



**Figure 2.9: Hottel-Whillier-Bliss plot**

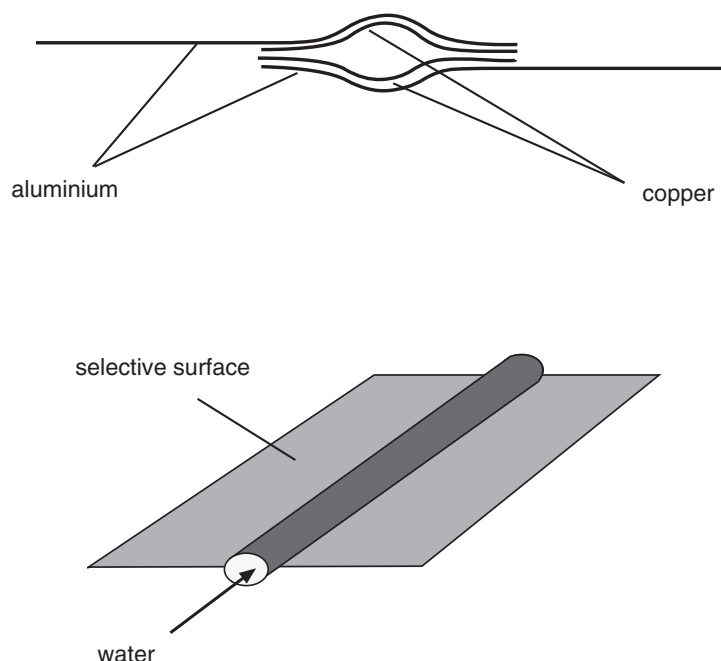
Performance figures obtained by Benseman and his collaborators in the early 1980s for the electricity savings achieved by domestic solar water heaters ranged from 200 to 700 kWh per square metre per year with the best unit (“COLT”) giving from 400 to 700 kWh per square metre per year, depending on the temperature setting of the cylinder thermostat within the range 50°C to 70°C. The most modern equipment can be expected to have a similar performance so a figure of about 550 kWh per square metre per year is frequently assumed for a cylinder thermostat setting of 60°C. This in turn leads to the frequently quoted 2200 kWh per year for a 4 square metre installation. In the 1980s when Benseman’s report was written, this corresponded to up to 75% of the household requirement. Many of the installations of that era were 2400 x 1200 mm panels with an actual collector area of 2.8 m<sup>2</sup>, which proved fairly satisfactory.

### **Panel design**

The performance of a flat plate, tube-on-sheet collector depends on the surface of the absorber, on the material of which the absorber sheet is made, and on the spacing of the risers. A matt black surface has a high absorptivity and emissivity for all wavelengths of radiation and therefore it is the most commonly used surface. Until recently, the absorber sheet was made of copper to provide high thermal conductivity from the sheet to the risers. In a typical all copper unit, the spacing of the risers was about 150 mm. With the increased price of copper, various attempts have been made to reduce its use for the absorber sheet. The most common replacement is aluminium, which has a conductivity about half that of copper. If this were the only change made, it would result in a drop in the collector performance. To offset this loss the risers can be put closer together or thicker sheet material used. Both of these measures will result in a partial loss of the cost advantage gained by the change away from copper.

More recently, aluminium has become available with a selective surface coating. Such a surface has a high absorptivity for radiation of solar frequencies but a low emissivity at its own temperature. This means that for a given input intensity the surface will operate at a higher temperature than a simple matt black surface. The higher operating temperature offsets the lower conductivity of aluminium and helps to maintain the performance of the panel. The other problem with copper tube on aluminium sheet collectors is that of obtaining a good thermal bond between them. This is a design area in which several solutions have been adopted by different manufacturers of aluminium/copper collectors. One material used for collectors, “Teknoterm”, has thin aluminium and copper sheets roll-bonded together in such a way that the copper can be hydraulically expanded to form a tube which is integrally bonded to aluminium fins (Figure 2.10). This material is used in “Solar Solutions” and “Sola 60” collectors.

A different approach uses the “heat pipe” effect to obtain a high thermal conductivity using steel, a material that has only one tenth the thermal conductivity of copper. A heat pipe in its simplest form consists of a tube from which all air has been removed and into which a small quantity of volatile liquid has been introduced.

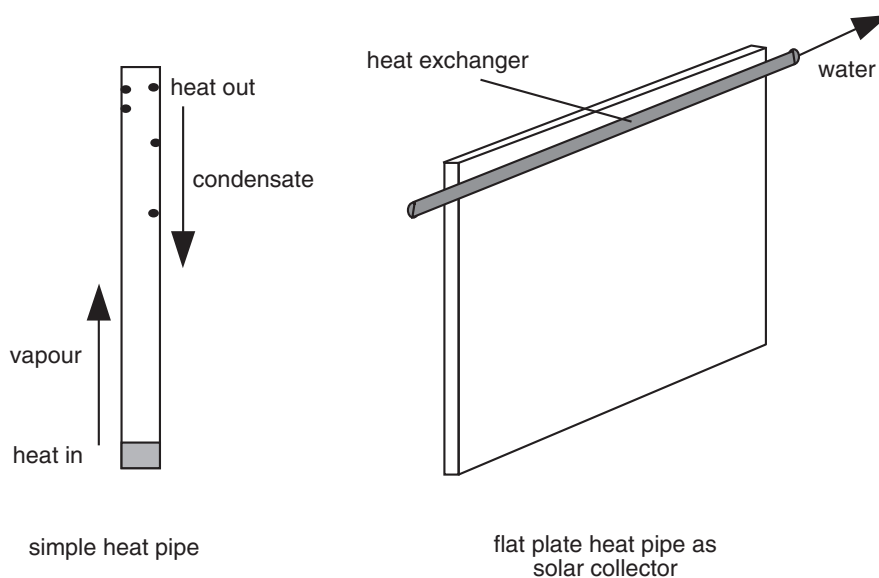


**Figure 2.10: Teknoterm solar collector based on bonded aluminium and copper sheets**

Such a device conducts by evaporation and condensation of the enclosed liquid and has a thermal conductivity that is virtually independent of the material of which the tube is made. A simple steel or copper heat pipe can have an effective conductivity more than a thousand times that of copper. The “THERMOCELL” solar collector uses a flat plate version of a heat pipe as shown in Figure 2.11.

Because of the high conductivity of the sheet it is only necessary to solder on a simple water-carrying copper tube heat exchanger near the top edge of the absorber. Since the working fluid in the Thermocell panel is a hydrocarbon, the steel does not come into contact with water and there is therefore no internal corrosion problem.

Another heat-pipe based collector is the “Thermomax”, which uses a tubular heat-pipe enclosed in an evacuated glass tube, as shown in Figure 2.12. A bank of tubes forms the collector.



**Figure 2.11: Thermocell solar collector based on the heat pipe principle**

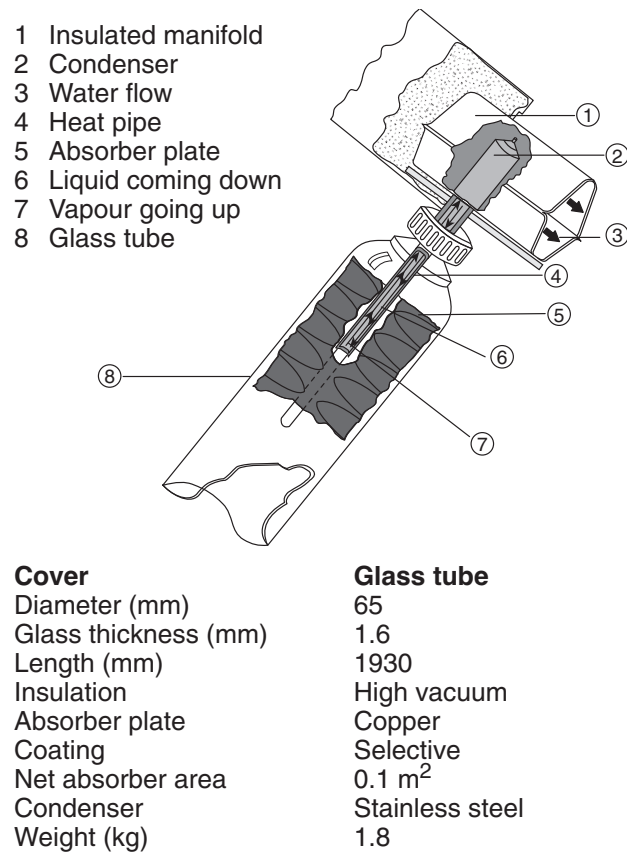


Figure 2.12: Thermomax evacuated tube collector

An alternative approach to the use of steel has been adopted by another manufacturer, “Solahart”, in which the double-walled absorber sheet has water circulating in it and through a jacket on the hot water cylinder, which acts as a heat exchanger to the water inside the cylinder. In this arrangement, the only metallic heat transfer is through two thicknesses of metal and the primary circulating fluid can be loaded with anti-corrosives to prevent rusting of the steel. A similar structure using stainless steel rather than mild steel is also manufactured by “Edwards”. The close coupled thermosyphon usually has the water cylinder mounted on the roof as an integral part of the collector structures shown in Figure 2.13.

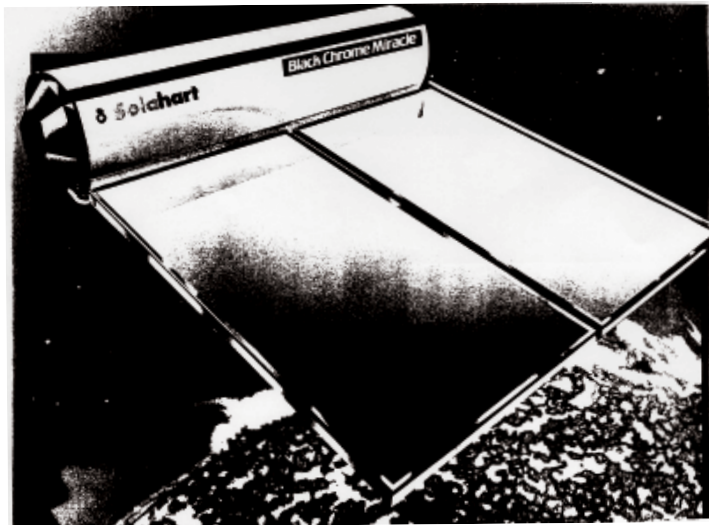


Figure 2.13: Solahart

Yet another collector that has recently made its appearance is made entirely of plastic. An absorber sheet and storage tank are integrally moulded of heavyweight polyethylene. Cold water enters the absorber at its lowest point and as it is heated it convects upwards into the storage tank. The tank and the back of the absorber are insulated with polyurethane foam and the front of the absorber is covered with a clear acrylic sheet. The design eliminates corrosion, reduces the risk of leaks and its slight flexibility provides an inherent protection against frost. The current model was designed for freestanding operation with no provision for electrical boosting and in this form would be suitable only as a preheater to a conventional hot water system in New Zealand.

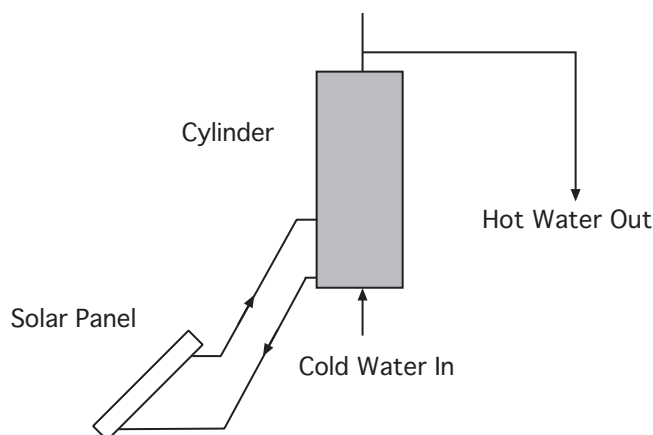
Consequently, there are now on the New Zealand market a range of well-designed, robust, well-performing, relatively low cost solar collectors.

### **System layout**

The complete solar water-heating system consists of the collectors and the storage tank and the means by which these are coupled.

There are two major arrangements of solar water heating systems in common use. The thermosyphon systems and the pump circulated systems.

Thermosyphon systems use the temperature of the water in the collector to provide the circulation as shown in Figure 2.14.

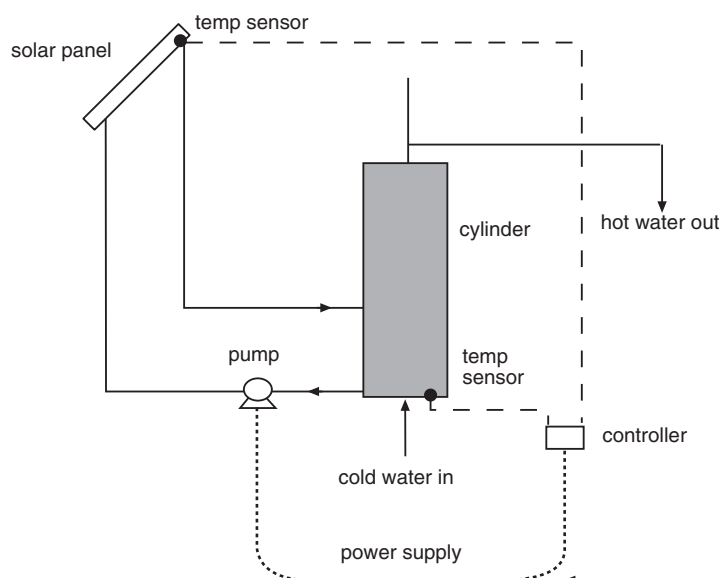


**Figure 2.14: Thermosyphon circulation solar water heating system**

They have the advantage that there is no auxiliary equipment and no parasitic energy required to operate the system. The disadvantage of the thermosyphon arrangement is that there are tight constraints on the geometry of the system. In particular, the cylinder must be above the collector panels and there must be a continuous rise in the pipes connecting the collector and the cylinder. It is also necessary in frost-prone areas to provide protection from freezing of the pipe-work and panels. This is usually done by incorporating a “frost valve” that opens at a degree or two above freezing which allows a small flow of water through the panels to waste by draining the system during the “frost season” or by incorporating a low power thermostatically controlled heater in the body of the panel.

The pump circulated system, shown in Figure 2.15, uses a circulating pump and a control unit to sense the cylinder and the collector temperatures so that the pump can be turned on when there is hot water to be collected from the panel. The use of a differential controller allows the collection temperature to track with the rising temperature of the cylinder. The other function of the controller is to sense when frost conditions are imminent and to protect the panel by turning on the pump to circulate a small quantity of warm water from the cylinder. In areas where freezing conditions are common and long lasting, the system can be protected by coupling the panels to the cylinder via a heat exchanger. The primary circuit can then be filled with a non-freezing mixture, such as a mixture of food-grade propylene glycol and water.

There are on the market a number of control units ranging from simple analogue devices to sophisticated



**Figure 2.15: Pump circulation solar water heating system**

microprocessor-based units capable of performing a wide range of functions that can be changed simply by reprogramming.

A pump circulated system can be used with any relative positions of the collectors and the cylinder.

Solar collectors may be used with the various low pressure hot water systems and with medium and mains pressure cylinders. They may also be used in conjunction with log burners equipped with “wet-back” water heaters. In this application, care must be taken to ensure that the plumbing arrangements for the two heating systems are kept separate. Cross connections can lead to unsatisfactory operation of either or both systems. The design of the hot water cylinder is important to the effective operation of a solar water heating system and in the past some disappointing results have been obtained that were due to the system design rather than to the panels themselves. Some manufacturers of mains pressure cylinders expressed concern about having solar water heaters attached to their cylinders for fear that the temperatures might exceed the safe limit for the ceramic lining of the cylinder.

### **Installation**

The most common method of mounting solar collectors is externally on a north-facing roof surface. In general, orientations between NE and NW will provide good performance. The ideal angle for mounting is the latitude angle but again good performance can be obtained at angles in the range latitude plus or minus 20 degrees. Angles flatter than latitude emphasise summer performance and steeper angles improve winter performance. For solar collectors used in conjunction with wet-backs, the flatter angles are preferred. Facilities to alter the angle to suit the season can be provided.

Recently there has been a move in some systems towards installing the collectors integrally as part of the building structure (Figure 2.16). This is often architecturally more acceptable than externally mounted systems and has a number of small but significant technical advantages over external mounting.

### **Heat pumps**

It is relevant to consider heat pumps here as alternatives to solar collectors. Heat pumps can be thought of in thermodynamic terms as the inverse of heat engines. In a heat engine, the natural flow of heat ( $Q$ ) from a high temperature to a low temperature can be made to yield some mechanical work ( $W$ ), as described in Section 2.1. A heat pump can use mechanical work input to pump heat from a low temperature to a higher temperature in opposition to its natural tendency. In practical terms, a heat pump operating between ambient temperature to a convenient hot water temperature ( $60^{\circ}\text{C}$ ) can deliver heat equal to about 1.5 to 5 times the energy taken to drive it. The ratio of the delivered heat to the electrical energy consumed is called the coefficient of

performance (COP). The COP varies with the source temperature and for typical small heat pumps this will vary from about 1.5 at low ambients to about 5 at high ambients. Thus a heat pump can provide a hot water supply using from 33% to 80% of the energy that would be required by a simple electric heater, depending on the conditions. This is similar to the capability of a typical solar water heating system, most of which are sized to supply 50% to 70% of the energy requirement of the system.



**Figure 2.16: An integral system of solar thermal panels incorporated into the building design**

There are two makes of heat pump on the New Zealand market designed for domestic water heating, “Quantum” and “Hot Shot”. Quantum is an integral system including the hot water cylinder and is designed to take advantage of solar energy as a booster to the heat pump. Hot Shot is designed as a direct air-to-water heat pump and can be attached to an existing hot water cylinder.

As a first approximation, both solar water heaters and heat pumps can save electricity to around two-thirds of the amount normally required to provide a domestic hot water supply. Their characteristic behaviours are somewhat different in that an appropriately sized solar water heater can supply almost all the requirement some of the time and none at other times, while the heat pump can supply much of the requirement some of the time and some of the requirement all of the time. In both cases, a system sized to provide all of the requirement all of the time would be greatly oversized for those times when operating conditions were good. Both systems, therefore, need some direct electrical or gas back-up heating.

The heat pump is often declared to be an example of “beneficial electrification” in that it will do a heating task with 30% to 50% of the energy input of a direct electrical heater. However, in judging this, one should take into account the energetics of the generating system. Where the electricity source is hydro, the saving is real but if part of the generating system is gas-fired thermal, then the electricity generated about 35% efficiency in terms of gas energy consumption and the heat pump simply compensates for this. Hence if the opportunity exists to use gas directly for water heating, this is generally a preferred option. This comparison is illustrated in Figure 2.17, where 20 energy units are lost when using direct gas firing and 68 energy units lost in the thermal power station and heat pump combination.

The combination of solar pre-heat and gas polishing may also be a desirable option if it replaces some gas-fired electricity generation. If gas/thermal electricity generation used for water heating is replaced by solar/direct gas water heating, the overall saving in gas will be about 90%.

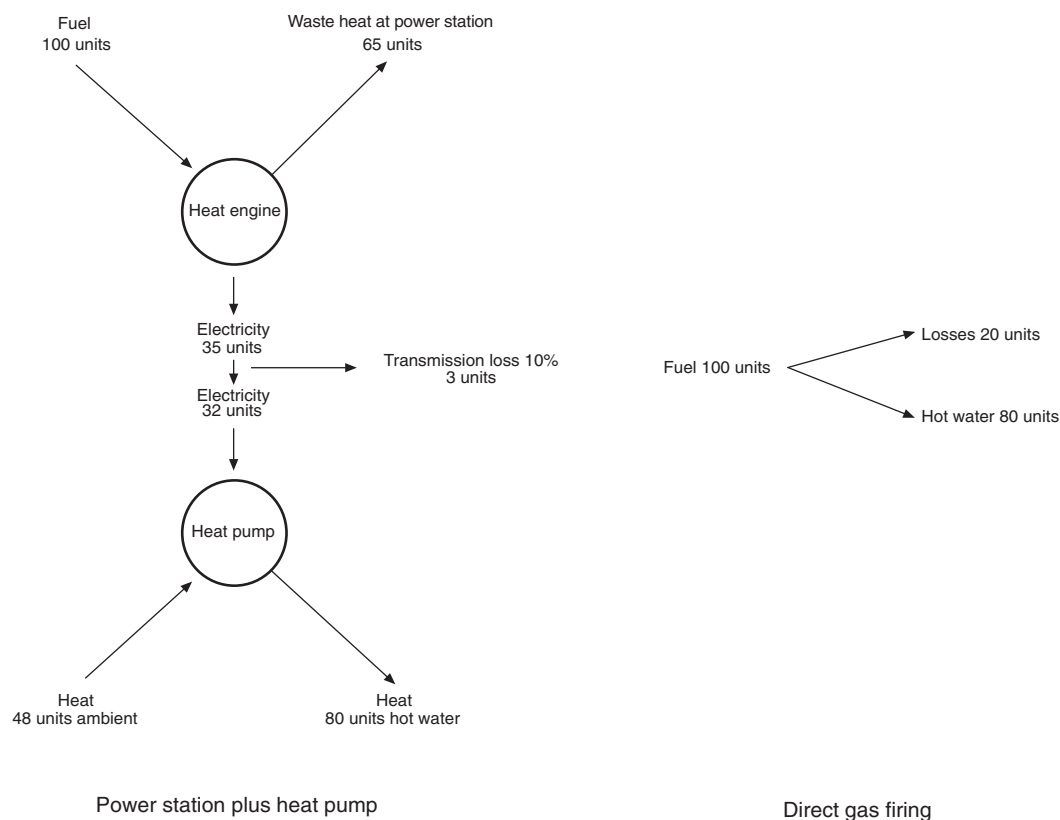
## **2.2.2 New Zealand Experience**

### ***Potential for solar water heating***

#### ***Ultimate***

Although it would be technically possible to install solar water heating on all of the estimated 1.2 million occupied residences in New Zealand, that option is neither economic nor feasible in the immediate future. The likely maximum rate of installation following an aggressive solar water heating education programme would





**Figure 2.17: Direct gas heating versus electricity from a thermal power station and heat pump**

be the rate of installation of new hot water cylinders. This has been estimated at around 60,000 per year (about 20,000 new houses and about 40,000 retrofits), which is consistent with a housing stock of 1.2 million and a typical cylinder life of about 30 years.

At a mean electricity saving of 2500 kWh per installation per year, total potential savings would be about 1500 GWh per year or the equivalent of the output of a hydro station of about 350 MW installed capacity. An aggressive installation programme could achieve this at the rate of about 30,000 installations per year over a period of 20 years. The savings achieved would compensate for a growth of about 75 GWh per year in other uses of electricity or about 0.25 % of current electricity demand per year.

The likely maximum uptake would, in terms of the evidence of cities with high solar water heating uptake, be about 50% of all houses.

### *Present activity*

From a survey of the major suppliers by Professor Arthur Williamson, the current installation rate of domestic solar water heaters (1995) is estimated to be about 1000 per year. A parallel survey by EECA indicates a slightly lower figure of about 700 installations in 1995 and an average growth rate over five years of 14% per year. This growth is indeed the major change in the solar water heating scene in recent years.

### *Future industry development*

There are presently six to eight companies manufacturing and marketing this total of 700 to 1000 solar water heaters per year in New Zealand.

If the industry grew to produce 30,000 installations per year, it would provide employment for an estimated 400 to 800 people in production, sales and installation. It would support four to eight large manufacturing operations and would depend on over 100 individual installers. It would probably take three to five years to bring the industry up to this rate of production.

### 2.2.3 Environmental Aspects

According to a study done at Canterbury University, the energy collected by a modern solar water heater in its lifetime is about 30 to 35 times the energy content of the device itself.

Over the last few years, the emphasis on energy use has shifted from energy sources to atmospheric pollution. A fully-developed solar water heating programme, as outlined earlier, would obviate the discharge of about 750,000 tonnes per year of carbon dioxide from a natural gas-fired dual-cycle power station.

The visible part of the system is the solar collector (and sometimes the water cylinder as in Figure 2.13) which is usually placed on the house roof and is generally considered visually acceptable.

The environmental impact of solar water heating system manufacture is limited to that associated with the normal production of the component materials such as steel, copper, plastic, glass and insulation. While there is no production of waste during use, there may be a small amount of solid and liquid waste for disposal at the end of the unit's operating life.

### 2.2.4 Constraints and Opportunities

#### *The barriers to a solar industry*

The barriers to the uptake of solar water heating are partly perceptual and partly financial. For many years, solar water heating has been seen as an area for amateurs. Because it has been possible for individuals to construct a more than adequate system from surplus materials and second-hand components, the industry has acquired a "non-professional" image. This has to some extent been fostered by professional engineers in the energy area who are attracted to more technically sophisticated systems. There was in the 1970s some justification for this view in the proliferation of solar water heater designs. A number of these were marketed by "backyard" businesses and a few were ill designed and badly made. There were also a considerable number of imperfect installations of good collectors in which the results were disappointing, particularly of thermosyphon equipment. Most of the 30 or so companies that were marketing in New Zealand in the late 1970s have now disappeared. There remain a few that have concentrated on systems that have a high performance/cost ratio and are well constructed. With the recent growth of the industry, there are a range of technically sound systems available and the knowledge base of installers is being rebuilt with fewer of the errors that were made in the 1970s.

The other major barrier, that of cost, has changed in some ways. Until recently, domestic electricity costs were low and interest rates were high. Solar water heaters were relatively expensive and the simple pay-back time for a solar water heater was in the range 15 to 20 years. There was little attraction in buying a solar water heating system on which the return in electricity costs avoided was about 5% to 10% when the bank gave 20% on a call account. Now, however, while the return on a solar water heater is usually in the range 8% to 12% (equivalent tax paid) the return on a bank call account has fallen to around 7% to 8% (before tax). From the point of view of the domestic investor, the relative value of solar water heating has thus improved significantly over the past ten years.

The third barrier to the implementation of solar water heating is the conservatism of the building industry and the lack of familiarity of the various professions and trades with this technology. There is a reluctance on the part of architects, builders and plumbers to become involved in installing new technology with which they are unfamiliar but for which they believe they will be held responsible. In this respect, it is probably worth studying the reasons why log burners, which were unusual and infant technology some ten years ago, are now a commonly used and "mature" technology.

There is a need to educate not only the potential users, but also the trades and professions involved in alternative energy systems. There is also a need for a more complete comparison between commercial and domestic economics of alternative systems. "Commercial" analyses often compare electricity production costs between large conventional generation systems and the alternative sources. However, domestic economics need to compare the savings at the cost to the householder of electricity (including GST) from the purchase of energy-saving equipment with the net return (after tax and surcharges) of investing the same amount in a conventional way (such as term investment in a bank).

### **2.2.5 Conclusion**

In summary, solar water heating is a developed and proven technology with a choice of equipment and suppliers available to the consumer. There is a need for some education of the consumers, architects and trades involved and the market will then grow. Heat pumps have a place in the domestic water heating scene, but this must be established in terms of a holistic analysis. There is a need for relevant economic analyses of alternative energy systems where the consumer provides capital. The cost of solar water heating will come down significantly due to economies of scale when a major market develops. Further research is warranted on selective surfaces.

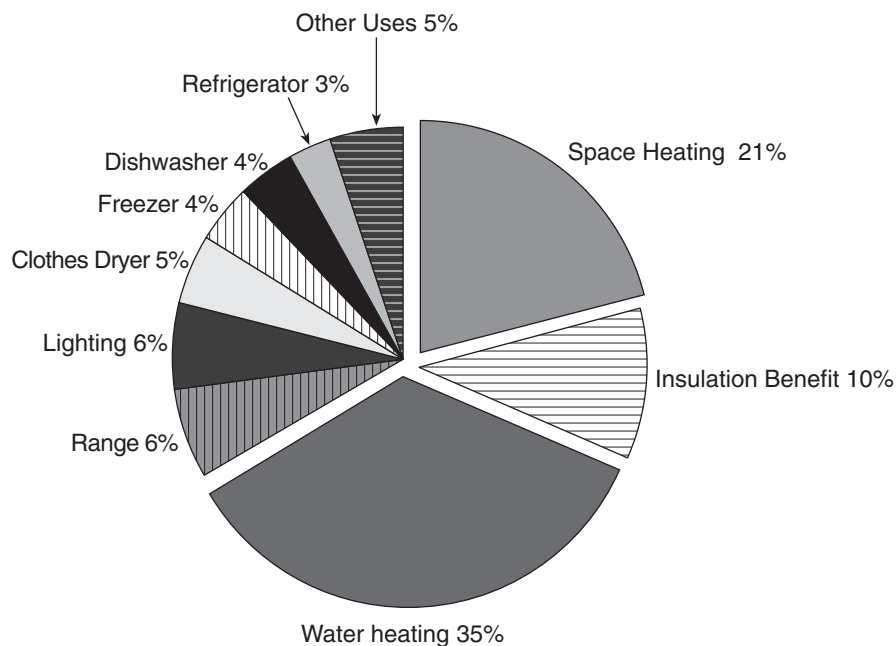
## 2.3 Passive Solar in Buildings

The principles of passive solar architecture are well developed and proven. Arguably one of the most outstanding buildings in the world is the passive solar worship building at Drogheda, located north of Dublin, Ireland. Drogheda has one central crucifix-shaped chamber, which is constructed of huge slabs of stone. The building is extensively earth mounded and has only one doorway, above which is the sole small window. Among Drogheda's remarkable features is the passive environmental control. Despite both the door and window being permanently open to the harsh Dublin climate, the temperature in the chamber is passively maintained at a constant 19°C for all of the year. The building also has a perfect daylighting regime in that a bright shaft of daylight precisely strikes the intersection of the floor and back wall of the chamber at sunrise on the solstice. This building has never leaked. It is also older than the pyramids!

Despite solar principles having been known since early civilisation and refined particularly in the latter half of this century, there is a low adoption rate in New Zealand. Although data on the patterns of energy use is incomplete, there is a growing concern that contemporary buildings may be increasing in energy consumption, rather than decreasing.

This section examines the opportunities for the utilisation of passive solar energy architecture. Commercial and domestic buildings in New Zealand represent a significant consumer of energy. Electricity is presently the major energy medium, with smaller quantities of fossil fuels, solid fuels and only a small amount of passive solar.

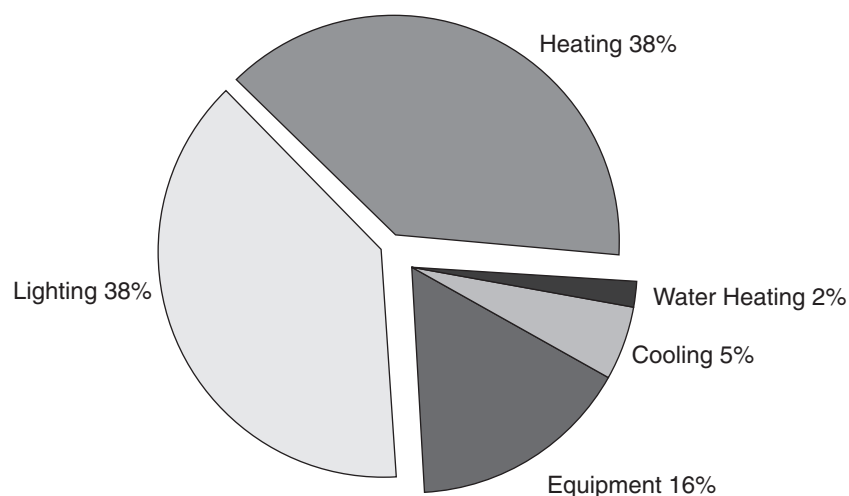
New Zealand's household sector accounts for approximately 14% of total consumer energy, and for nearly 35% of total electricity use. The major uses of purchased energy in a typical New Zealand house are space heating and water heating. New Zealand's housing stock is over 1.2 million housing units. Of these, approximately 30% are built to comply with the New Zealand standard NZS 4218P and purchase between 5000 and 11,000 kWh of heating each year. The owner of an uninsulated or partially insulated house that was not built in accordance with the standard would have to purchase considerably more (up to double) the net energy for heating. Typical energy uses by activity for a house insulated to NZS 4218P:1977 and built in Wellington are summarised in Figure 2.18.



**Figure 2.18: Typical energy use by activity (Wright & Baines, 1986, in Isaacs, 1995)**

In office buildings, over three-quarters of the purchased energy is consumed by the building services. The pattern of energy used will vary greatly with the level of amenity provided and the internal loading. Lighting

is usually one of the larger energy consumers, and appliances are usually the least. Estimates for the energy end uses for an internally load-dominated office building in Wellington are shown in Figure 2.19.



**Figure 2.19: Energy end use for an internal load dominated office building**  
(Isaacs, Baird & Sterios, in Isaacs, 1995).

Compliance with traditional building practices provides, by default, some degree of natural lighting, heating and cooling. However, consideration of the building's orientation, configuration, envelope design and the construction materials lends considerable scope for harnessing the free natural resources of the sun, breeze and ambient external temperature. Energy savings in a "low energy building" can typically be estimated at up to 80% over traditional residential construction, and 40% for standard office buildings.

It is considerably less expensive to incorporate passive solar measures at the time of construction than to install as a retrofit. This allows for a holistic consideration of the energy demands and supply, in response to the users' requirements and local environment.

Passive solar technologies have advanced since the early experimental housing of the 1960s and 1970s. State-of-the-art examples, such as the 100% self-sufficient solar house in Fraunhofer-Gesellschaft, Freiburg, Germany, use both passive solar systems such as photovoltaic generated power and transparent insulation, and active systems ranging from pumps and ventilators to a pressure electrolyser to store excess summer insolation by converting water to hydrogen gas. The gas equates to 1500 kWh of energy, which is stored in underground tanks at 30 bar pressure. When required, the gas is either converted to electricity by way of a fuel cell or catalytic combustion for cooking heat.



**Figure 2.20: Passive solar house at Fraunhofer-Gesellschaft, Freiburg, Germany** (Fraunhofer Institut für Solare Energiesysteme, 1992)

The main opportunities for increasing the utilisation of passive solar energy in buildings include solar space heating, natural cooling, and daylighting.

### **2.3.1 Technology Review**

#### ***Space heating***

Solar heating includes four concepts:

- solar collection;
- heat storage;
- heat distribution; and
- heat conservation.

A great advantage of solar heating principles is that they can be utilised in a building for space heating at either low levels to supplement other sources, or as the primary means. New Zealand domestic case studies have shown that free radiant solar heat can be the sole source of warmth. International examples are showing that high utilisation of solar heating is becoming more common for commercial buildings. Full adoption is limited, possibly due to competition from other design and user considerations, and a desire for short-term paybacks.

British Department of Energy sponsored research has “clearly shown that the dominant factor in the design of a low energy (commercial) building is the minimisation or avoidance of air conditioning” (Shaw, 1994). This research has shown the benefits of the judicious exposure of the building’s structure as a primary thermal mass to moderate diurnal temperature swings. Incorporating thermal mass with the space for the user has the limitation that net temperature gains will occur, especially in summer, unless the free resource of cool night air is used to purge accumulated heat. Although night purging will utilise some fan power, it has the advantage of simultaneously removing indoor air pollutants and moisture from within the space.

Studies in Sweden have shown energy efficient benefits of pre-conditioning the inherent thermal mass of the floor structure by blowing air through the hollow cores of the floor slab. Air velocities are kept low due to the surface roughness; consequently the fan power can be kept within the recommended ASHRAE (American Society Heating, Refrigeration and Air Conditioning Engineers) range. This system has a low capital cost and achieves efficiencies through excellent thermal coupling between the air and the structure. This can be used for either radiant heating or cooling. The main limitation with this system is its slow response time, in that it cannot deal with rapid demands from occupant activities.

The use of phase change materials is widespread for bulk storage of heating or cooling air in air conditioning systems. Research at the Building Research Establishment (BRE) in England is investigating the potential of using phase change materials close to or within the occupied space. These materials can be incorporated into the building fabric in a palletised form or as a coating. They allow a substantial increase of thermal storage without an undue increase of building mass or volume. Initial results on the latent heat and temperature fusion are promising but further investigations are required of other properties, such as durability and toxicity.

The means of providing higher values of insulation are well established. New naturally occurring insulation products are now being marketed, such as wool and cocoa nut fibres. Dacron is another alternative with low embodied energy. Research is being undertaken to improve the fire and slump resistance of these materials. Increased insulation has the advantages of preventing the escape of interior heat in winter and indirect conducted heat gain in summer. It also provides increased thermal comfort for occupants seated close to an external wall. During cool weather, they are not radiating body heat to a cold wall surface, hence they will feel comfortable at cooler air temperatures. It will also moderate vertical and horizontal temperature gradients, which increases the occupant’s comfort.

The heat loss through uninsulated glazing can be ten times as much through a wall with average insulation. Improvements have been made in the design of double and triple glazed windows. When combined with argon gas and low emissivity coatings, they have excellent heat admission and retention properties. Even south-

facing double glazing in Invercargill can have a net solar heat gain (Pool, 1993). Double glazed windows have additional advantages of eliminating condensation and noise intrusion, but they are still costly components.

### ***Natural ventilation and radiation control***

The dilemma of passive solar heating is the requirement to control unwanted radiation and overheating. This involves the principles of:

- control of direct solar radiation;
- control of indirect conducted heat gains through the building's envelope; and
- ventilation and air exchange.

Advances in the interception of direct radiation include active devices such as movable shades and beads, and passive devices such as holographic films. Moveable shading devices track the path of the sun and tilt to prevent the entry of slits of low altitude sunlight that would cause overheating and glare. They are, however, reasonably high capital cost and maintenance items. External shades have the advantage that they can be retrofitted and will give considerable energy savings, especially for commercial buildings with large expanses of glazing.

Innovative window frames can now provide fixed or operable vents within the window frame that provide for natural ventilation without compromising security or causing undue draughts. This is an advantage for solar heated structures. For commercial buildings installed with energy management optimising software, motorised window vents could also provide an alternative to mechanical chilling for discrete building zones.

New glazing materials that can reduce radiant heat gain or loss include low emission coatings selectively coated on the inner surface, polychromatic glass that darkens as the light brightens, and liquid crystal display (LCD) smart glass controlled by a small electrical current to change from clear to opaque.

The popularity of atrium spaces in multi-storey commercial buildings also provides good opportunities for natural ventilation and solar heat and light collection.

Passive ventilation is limited to sites with clean outdoor air and low ambient noise pollution. On busy urban or industrial locations, it is preferable to draw air in at high level and use best practice mechanical systems.

### ***Daylighting***

Innovative natural daylighting involves the strategies of:

- controlling the direct solar radiation close to and through the windows;
- reflecting radiation deeper into the floor plan to give a more uniform light distribution;
- controlling glare and the quality of daylight so it can be used as an effective working illuminant;
- reduction of solar heat gains; and
- optimising combinations of daylight and artificial light makeup.

It is commonly assumed that optimising natural daylighting has the single greatest potential for reducing energy consumption in commercial buildings. As lighting in office buildings can contribute up to 30% to 50% of the energy consumption, new passive technologies are expected to reap considerable rewards. Overseas research suggests that total energy consumption can be reduced by 20% to 40% with simple low cost daylighting schemes. As lighting loads normally coincide with peak electricity loads, considerable economic savings can be achieved. The applicability of these schemes is being tested in New Zealand (Isaacs, 1993). Natural lighting is a win/win energy option, as it also reduces the incident internal heat gains. Daylight provides more lumens of light per Watt of heat output than even energy efficient fluorescent lamps.

Passive systems include holographic films, prismatic glazing, prismatic films and lighting shelves. Considerable research and technological developments are taking place in these areas.



Holographic films redirect light by diffraction. The film is embedded with miniature louvres that intercept high incidence solar radiation while allowing the entry of lower incidence winter light. Various effects can be created, including the refraction of light so a significant proportion is directed onto the ceiling and deeper into the room space. This achieves a more uniform lighting distribution and a reduction in glare. Another advantage is the freedom of window geometry. Unfortunately with the present technology, the refraction scatters the light spectrum, causing unacceptable colour separation (De Herde, 1994).

Prismatic glazing refracts certain angles of incoming light whilst allowing other angles to enter the building. Through these selective transmission characteristics, it is possible for diffuse daylight to be utilised for lighting, while unwanted solar radiation (and heat gain) is redirected. Prismatic glazing has been found to give good all round control of daylight and reduced glare under differing seasonal conditions and degrees of cloudiness (Littlefair, 1994). For prismatic glazing to be most effective, some solar tracking is required. At a cost, the tracking motorisation can be incorporated into the building management system to achieve a fully integrated system.

Other developments in reflecting natural light deeper into buildings include the design and placement of light shelves to optimise light but minimise solar heat. Light shelves often include curved louvres on the upper surface to reflect light deeper into the room plan and consequently create a more uniform illuminance. New high tech materials are being trialled to capture light by means of reflexive panels, laser cut glass and Fresnel's lens, and transfer this through reflexive layers and optical fibres (Sala, 1994).

Internationally, the technologies for improved energy efficiencies are mature and slowly gaining market acceptance. There is considerable latitude for further energy efficiency in both the new and existing building stock.

### **2.3.2 New Zealand Experience**

There are many successful "energy efficiency" commercial projects where changes to the artificial lighting, HVAC (heating, ventilating and air conditioning) services, insulation (mainly of HVAC equipment) and building controls have rewarded the building user with typically 20% to 50% energy savings, giving payback periods between 3 months and 4 years. Many of these successful projects were retrofit installations where the savings are clearly evident from a 'before and after' usage pattern. There is considerable further opportunity to reduce the dependence of mechanical environmental systems with renewable passive measures.

Commercial buildings based principally on passive solar technologies are the exception, representing under 1% of total building stock. New Zealand's climate can support low energy passive solar buildings. Given the appropriate design and conditions, this can be achieved without substantial increases in construction costs. Building consultants are reporting increasing activity in this area and there are several significant new projects in the pre-construction phase.

The Nelson Public Library is an excellent demonstration of the economic viability of passive solar in New Zealand (Figure 2.21). The library uses approximately 40% less energy than is normal for other comparable buildings (CAE, 1996). The passive strategy included:

- external shades, which limit peak summer sun and reflect light into high level windows;
- a central courtyard to admit daylight and natural ventilation deep into the floor plan;
- clerestory windows to provide daylight as the primary light source for 75% of the working day;
- operable windows and louvres, and ceiling mounted fans; and
- higher than normal levels of thermal insulation.

The building was located on a difficult site, which constrained the building's orientation and limited windows on the north face, thereby reducing the viability of solar heating. Energy modelling of the building proved that a comfortable indoor climate could be created without the need for mechanical air conditioning (Donn, 1996). Passive environmental controls achieved significant savings both in capital costs (\$70,000) and operational costs (\$8400 per annum). The modelling and associated design work only added \$24,000 to the project cost.



**Figure 2.21: Daylighting in the Nelson Public Library (Courtesy of the Centre for Building Performance, Victoria University)**

Houses with a high utilisation of solar energy exist in many climatic zones of New Zealand, from Auckland to Invercargill. Some of these employ a combination of passive solar, photovoltaic and solid fuel, and are self-sufficient from the grid. However, these are still very much in the minority. Demonstrations such as the Wellington City Council's Eco Home will boost public awareness and confidence of the savings that can be achieved without comprising comfort or capital cost. The Wellington Eco Home was commissioned by the Wellington City Council as a show home built on a small inner city site to demonstrate the ecological advantages of passive solar principles, low toxicity paints and materials, and energy efficient design. It is an all-electric dwelling sponsored by ECNZ and designed to provide a new benchmark in energy efficiency of houses.

### ***Current energy resource and potential***

It is estimated that the total solar energy falling on the roofs of New Zealand houses was equivalent to 600 PJ annually (Harris 1977, in Isaacs 1993). This compares to the 1991 total domestic energy consumption of 52 PJ (Massey University, 1992). Since this estimate, the total roof area has increased by approximately 300,000 household units, giving a further 200 PJ of insolation reduction. The incident solar radiation on domestic structures will continue to increase at approximately the same rate as the number of new households.

The disadvantage of this energy source is the seasonal and diurnal variations, which will always require either a means of energy storage such as thermal mass and/or an alternative energy source. There are variations in the distribution of solar energy both regionally and locally from localised shading and microclimates. The hilly topography of many areas can prevent optimum orientation of many buildings.

A feature of the New Zealand climate that aids the viability of passive solar is the high proportion of winter sunshine hours. The South Island, which has the greatest energy need for space heating, is fortunate to have clear winter skies, with the exception of Southland. A large proportion of the country has at least 2000 annual hours of sunshine. Annual sunshine ranges between over 2400 hours in Blenheim, Nelson and Whakatane, to a low of less than 1700 hours in Southland and coastal Otago (Isaacs, 1993 and Figure 2.4).

The average daily insolation for all of New Zealand is  $4 \pm 10\%$  kWh/m<sup>2</sup>. This varies from a mid-summer high in the northern most latitudes of 6.5 kWh/m<sup>2</sup> to a mid-winter low in the south of 1.0 kWh/m<sup>2</sup>.

The area available for heat collection in commercial applications is less than the area available in low and medium density housing. However, the heating demand is also lower due to internal heat gains and a reduced ratio of external surfaces to internal volume.

## **2.3.3 Environmental and Social Aspects**

The utilisation of solar energy neither adds nor detracts from global energy flows. Passive solar design in buildings results in only normal building wastes.

On the localised scale, it may have a slight impact on the aesthetic environment, however building features can be designed attractively or otherwise. Many passive solar features can, if so desired, look the same as their conventional equivalent. Alternatively, passive solar features designed to appear obviously different create the opportunity to spark interest and awareness.

Provided that attention is paid to good design, problems such as glare and overheating will be removed. Occupants can benefit from more comfortable interiors (light, airy conditions, improved view) and the external architectural appearance can be much improved.

Passive solar design does not contribute to emissions of CO<sub>2</sub> or other climate changing gases. It can assist to lower the total national production if utilised as an alternative to other purchased CO<sub>2</sub> producing energy sources.

There is a need for building purchasers to take a longer term view of both the environmental and economic consequences of a building's energy demands. There is some evidence of investors in the European property market giving favour to environmentally green buildings. It is not apparent if the motivation is from economic gain, ethical considerations, social conscience or other. Discussions with local property brokers suggests that this market trend is not significant in New Zealand, although there is no formal research that investigates the priorities of building purchasers.

A substantial barrier exists with the split between the owner who pays for the capital investment of passive solar, and the tenant who reaps the ongoing energy savings. In New Zealand, one-third of housing and one-quarter of commercial property is rented or leased. Although no formal research has been undertaken, it does not appear that the purchasers of rental property are discerning of the operational costs of a building and paying rentals which reflect these costs.

One possible reason for the low adoption rate of passive solar in buildings is the inherent lack of a "product" to sell or a defined market to sell to. Consequently, under free market conditions, there is a lack of a product champion to promote the design principles. This is an area where New Zealand society could benefit from a nationwide, funded promotion.

There are some behavioural implications for the occupants of passive solar homes, in that they need to be more aware of the natural heating flows, e.g. a need to take showers in the evenings and pull drapes to retain heat. These changed habits are not particularly onerous.

### **2.3.4 Economics**

In a recent report, it was "estimated that the technical potential over the next decade for solar energy applications in New Zealand may be about 2000 GWh per annum, or in the order of 7% of the current electricity demand" (EECA, 1996).

Passive solar buildings have the considerable advantage of reducing energy consumption at the point of the users. Therefore, estimates of total energy savings should also include savings in distribution losses and grid costs.

The average life of a New Zealand house is 80 years. Unless there are some rapid changes in current construction practices, the next three or so generations of New Zealanders will be lumbered with homes heavily reliant on purchased energy. It is a reasonable assumption that the cost of energy will increase as the resource of fossil fuels diminishes. As previously stated, passive solar strategies are considerably cheaper and easier to install at the time of construction.

A reasonable payback period is often cited as a barrier to the incorporation of renewable energy or efficiency measures. It is often assumed that a payback in excess of two years is not economically attractive for homeowners. This argument is short sighted when a two year payback period represents a return on investment annually of around 50%. This rate is especially attractive when compared to the current after-tax return on a bank term deposit of approximately 7.6%.

A passive solar building feature with a two year payback will be freehold in under 3% of the building's useful

life and will also have some residual capital value. As an investment, the capital value of passive technologies are not very liquid, but they are low risk.

The rate of return is not as attractive for passive solar investment for properties in the commercial sector, as purchased energy is a tax deductible expense, and the economic life of the building may be shorter. Few commercial buildings are designed, owned and tenanted by the same body, so there is less incentive and opportunity to incorporate passive solar technologies at the time of construction.

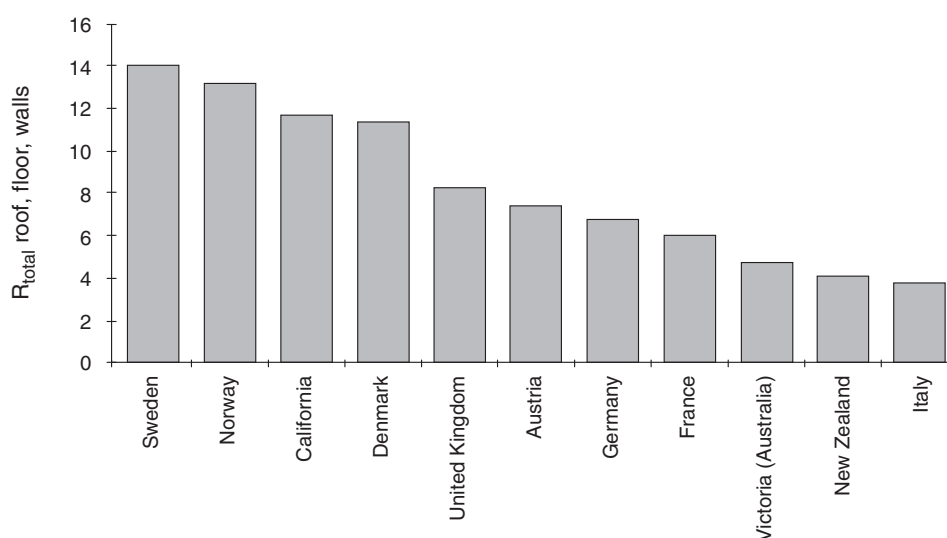
## 2.3.5 Constraints and Opportunities

### Space heating

With a national average of over 2000 hours of sunshine per year, it can be argued that all New Zealand buildings utilise passive solar energy to some degree. An opportunity exists to increase the degree to which passive solar is engaged. In part, this could be achieved simply by increasing the required level of insulation in new and retrofitting existing buildings (particularly pre-1978). A Building Research Association of New Zealand (BRANZ) study revealed that 18% of existing New Zealand homes have no insulation (Isaacs, 1993).

The introduction of the Local Government Act 1978 was the first attempt at energy efficiency in buildings, via the limited requirement for some insulation. The Building Act 1991 has the intention of an integrated approach to efficient energy use in buildings. The Act is regulated through the New Zealand Building Code 1992. The current regulations are still limited in scope to energy consumed in the process of controlling the indoor temperature. These regulations are in the process of revision, for implementation late 1996.

The present regulations for new buildings require a significantly lower insulation R-value for the building envelope than most other western countries, as summarised in Figure 2.22. (Isaacs, 1993). The building codes of most other countries stipulate a maximum glazing area, which is also not regulated in New Zealand. Even given differences in climate, New Zealand's new housing is under insulated. At present, there are no requirements or incentives to insulate commercial buildings, nor to retrofit older structures. The insulation standard, Clause H1, New Zealand Building Code, for both housing and commercial buildings is currently under review. Preliminary reports suggest that the new level will be based on a "politically acceptable" increase in the average house price, rather than on an optimum energy efficiency level.

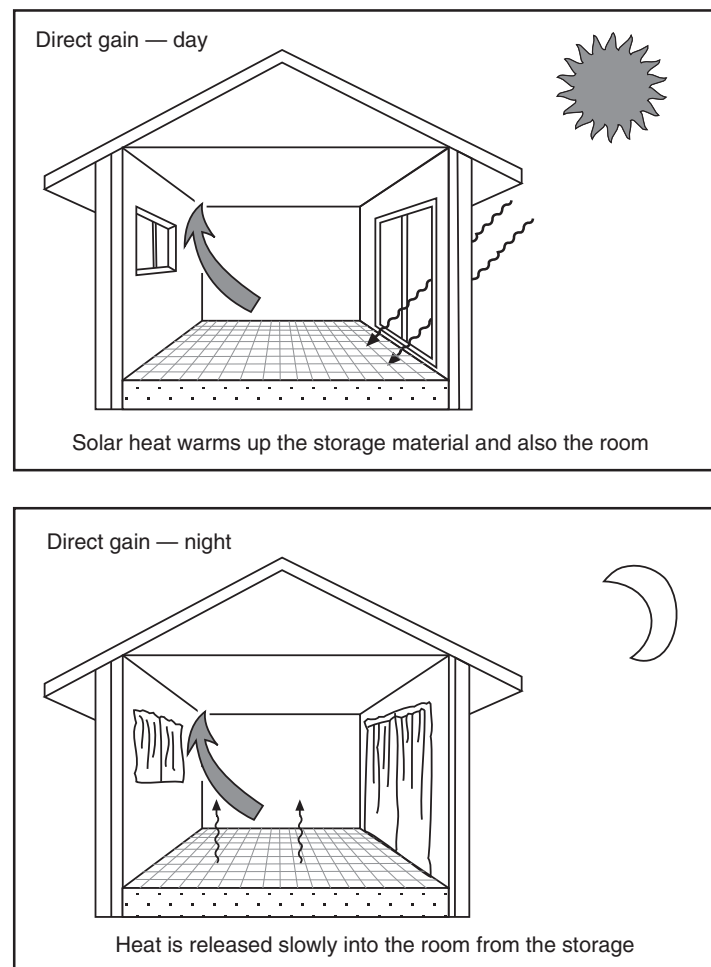


**Figure 2.22: Total thermal insulation requirements — a comparison of countries (Isaacs & Crust, 1993, in Centre for Advanced Engineering, 1996)**

New Zealand's existing housing stock of over 1.2 million was largely built prior to 1978, when insulation became mandatory. There are approximately 20,000 to 22,000 new homes built per year. Traditionally, New Zealand homes have very little thermal mass and less than 4% will have double glazing. Solar orientation was

a low priority design criteria in early homes. There is presently no requirement to optimally orientate a building for sun inclusion, and good siting costs no more. Without considerable outlay, there is little opportunity for implementing passive solar strategies in most existing houses, except for adding insulation and heavy drapes. Insulation is easiest installed in pitched roofs and under suspended floors where access is not limited.

Most new homes on flat or low sloping sections are constructed with concrete slab floors, as this is presently the cheapest construction. Although this represents a considerable increase in the thermal mass, there is seldom any net gain in heat storage as the thermal couple is broken by carpeting. Given appropriate design guidance, there is potential for heat storage to be effective in contemporary buildings without any changes in construction and marginal costs.



**Figure 2.23: Direct solar gain (Ministry of Energy, 1983, in Centre for Advanced Engineering, 1996)**

Only 9% of new homes are with fitted insulated glass windows and approximately 100 existing homes are retrofitted with double glazing per year. The average house has a glazing area of 40m<sup>2</sup>. There are many variables, but on average double glazing can save about 25% of a home's heat loss through the building envelope. Double glazing presently costs about \$80/m<sup>2</sup> more than an equivalent sized single glazed window. To double glaze all windows of an average house would therefore cost an additional \$3200 in construction costs. If this house consumed 10,000 kWh a year on space heating, at present electricity prices this would save \$250 per year in power bills, representing a payback period of 13 years. This simplistic calculation assumes zero inflation of the price of electricity and no residual value on resale. Shorter paybacks will be achieved for double glazing south facing windows, where heat losses are greatest.

Approximately 5% of existing homes have a conservatory space addition. Of these, less than 15% are appropriately designed to optimise passive solar heating principles. In many cases, coupled thermal mass,



ventilation, shading, etc. could be incorporated with minimal additional expense at the time of construction. Most conservatory installations are a net heat loss and a lost golden opportunity. Proposed changes to clause H1 of the Building Code will require that future conservatories be insulated to current code requirements.

There are no code requirements for energy efficiency of appliances or water heating. As domestic water heating represents 37% of a typical household's consumption, and efficient technologies are commercially available, there is considerable scope for savings.

### ***Natural ventilation***

The full potential of the natural ventilation resource is not understood, due to a lack of climatic data on the simultaneous occurrence of the need for cooling and either too much or too little wind. The majority of New Zealand is still fortunate to have an acceptable standard of outdoor air and low ambient noise levels. The Resource Management Act goes some distance towards protecting these rights, but does not cover vehicle emissions, which are the largest source of inner city pollution.

In densely populated inner city areas, the quality of external air, wind funnels and noise conditions are often not suited to natural ventilation. There is often an unfortunate mismatch between these external conditions and lightweight building envelopes, which have a heavy need for cooling.

As building construction methods become more airtight, deliberate ventilation is required to remove moisture and pollutants that accumulate in an interior. Given an appropriate design, low rise domestic and commercial buildings have ample potential to provide sufficient ventilation by means of protected openings, building shape and shading. New Zealand has an emerging group of specialist consultants with valuable experience in designing with natural ventilation.

### ***Daylighting***

Although energy inefficient, incandescent bulbs are the most common artificial light source in domestic installations. This is not expected to significantly change as patterns of use; short hours of operation, and frequent switching on and off of fittings seldom warrant installing low energy/high capital cost fittings. Most modern domestic buildings are designed for reasonable use of daylight. As the density of urban and suburban inhabitation increases, the protection of the right to daylight will need to be further addressed.

Many commercial installations are converting to energy efficient light fixtures and receiving short payback periods. There is considerable opportunity for optimising the natural light, especially as few areas of New Zealand commercial zones are overshadowed by other high rise buildings. The need and availability of natural light for most of the year are conveniently matched with typical office hours. As this coincides with high demand periods of electricity, the supply authority can also benefit from substituting electrical lighting with solar.

### ***Creating a market niche***

A labelling scheme to identify passive solar buildings could give financial rewards to the owners of such buildings at the time of sale or lease. Precedents for environmental rating schemes for buildings that consider energy efficiency, CO<sub>2</sub> etc. already exist in the United Kingdom (BREEM, Building Research Establishment Environmental Assessment Method) and Canada (BEPAC, Building Environmental Performance Assessment Criteria). These could be adapted for New Zealand conditions. The BREEM scheme has modules for domestic, commercial offices and retail, and has been used by developers as a marketing incentive.

## ***2.3.6 Further Research Requirements***

The requirements of future research, essentially fall into four categories.

**The capture of New Zealand specific climatic data.** Climatic data with a fine geographic resolution will enable accurate economic analysis and design solutions. This data should be built into design tools to demonstrate options and economic benefits.

The newly released data on insolation and solar availability compiled by Industrial Research Ltd (IRL) will

be of great benefit for the accurate planning and design of solar architecture. This data presently exists for five sites and will be useful, especially when it is expanded as planned to include 26 locations. This will enable more accurate energy and economic modelling at the feasibility stages of a project.

For the same reasons but relating to natural ventilation, New Zealand specific data is required on the correlation of wind (strength, temperature and direction) and sunshine hours.

**A study of the end use of energy in buildings.** This will improve confidence of models to optimise the viable technologies. Base information on the basic use of energy in buildings will clarify the energy consumption patterns and user interactions. This will focus attention on the areas where greatest savings can be achieved. It will also increase confidence in the savings that can be achieved from passive solar, and assist the comparison between differing renewable energy sources.

Estimates of obtainable energy savings differ in details between modelling packages (Pitts, 1994). More post-occupancy evaluations and monitoring of low energy buildings are required to validate and refine design models. More accurate estimates of potential energy savings are also required to help persuade building commissioners to invest in passive solar measures. These packages are primarily being utilised in the design of small-scale commercial and domestic buildings. There is also a need to bridge the gap between specialist design tools and non-specialist building designers. This should increase the accessibility of passive solar solutions to a larger market sector.

**The ongoing refinement of the technologies.** This includes both improvements of the design tools and the actual building construction. Improvements in the expert design tools are required to increase both their user friendliness and accuracy. Increased user friendliness will allow more designers access to passive solar solutions and would reduce the expertise required to drive the tools. Faster generation of appropriate solutions would reduce the design time and cost. More accurate tools for daylighting, ventilation, thermal storage, etc. will assist the modelling of the economic viability. They will also assist the iterative refinement of the most favourable passive solar solution.

**Identify and develop methodologies to overcome social barriers.** These are presently limiting the uptake of passive solar. There is need to overcome the barriers which are delaying the widespread uptake of commercially viable but under-utilised technology. Barriers are considered to include:

- a short return on investment period;
- lack of awareness of resource potential;
- a reluctance by property investors to incorporate capital expenditure which will return operational savings for tenants;
- a need for site specific design;
- a shortage of trained design consultants with appropriate awareness of the issues;
- a reluctance of building commissioners to employ specialist building designers;
- lack of regulatory driven requirements; and
- lower priority than or conflict with other design criteria.

Research is required to identify the importance which property purchasers place on these and other attitudinal barriers. Strategies can then be formulated to overcome these perceived problems.

### **2.3.7 Conclusion**

It is well proven that appropriately designed passive solar buildings can produce both energy efficiency and occupant comfort without comprising aesthetics or other environmental factors. The main barriers facing the full adoption of passive solar strategies pertain to the economic balancing of the capital cost versus energy savings, and the demonstration of the rewards. Attitudinal barriers will also need to be addressed.



The means for implementing passive solar construction are viable and commercially mature in New Zealand. However, their use is still predominantly limited to a “fringe” of environmentally aware users.

Advances in efficient usage can largely be attributed to increased awareness, education and economic rewards. Schemes such as the Beta awards (despite the strong electricity bias) and Crown Energy Efficiency Loan Scheme are vital in promoting energy reduction strategies. Free access to information and publications such as Energy-Wise News and CADDET reports (Centre for the Analysis and Dissemination of Demonstrated Energy Technologies) are beneficial in sparking awareness. These, however, are still only touching a very small percentage of the population and there is considerable scope for further improvement.

Experience has shown that the passive solar principles perform best when a holistic approach is taken, with consideration given to all building services, user activities, the building’s form and the relationship with the local environment.

There is a vision of a future era (a post fossil fuel era) when buildings will have intelligent shading devices, masses of insulation, self-sufficiency in thermal storage for heating and cooling, and artificial lighting fueled by energy generated and stored on site.

## 2.4 Photovoltaic Electricity

This section presents an overview of solar photovoltaic technology based on solid state materials. It does not address newer conversion methods that are still at an early stage of research, such as photoelectrochemical conversion and light harvesting by organic and other molecules. These are promising methods of harnessing solar energy, but generally are not expected to have a sizeable impact on energy matters in the next five to ten years and are, therefore, considered only briefly in section 2.5.

### 2.4.1 Technology Review

Direct conversion of sunlight to electricity can be achieved by the photovoltaic (PV) effect, which occurs in semi-conductor materials exposed to photons having energy greater than a given threshold energy. This threshold is dependent on materials and is equal to the “semi-conductor bandgap”. Its value and the spectral content of sunlight determine the most suitable materials for PV conversion. The most popular semi-conductor materials used in PV cells include the single element silicon (Si); and binary and ternary compounds such as gallium arsenide (GaAs), gallium antimonide (GaSb), indium phosphide (InP), copper indium diselenide (CIS), cadmium telluride (CdTe) and their various derived alloys.

Photovoltaic cells are made from these materials either in monocrystalline (single crystal) form (c-Si, GaAs, InP); multicrystalline and polycrystalline form (p-Si, p-CIS); or amorphous form (a-Si). In each case, laboratory production and the corresponding industrial scale production techniques differ and lead to different performance parameters and solar conversion efficiencies, ranging from 9% to 24%.

In all cases, a PV cell must fulfil three main functions efficiently and cost effectively:

- it must trap the maximum possible amount of the sunlight falling on it;
- it must convert the maximum amount of this photon energy into electrical energy; and
- it must make this electrical energy available at its terminals with minimal loss.

Accordingly, the cell usually includes three main structural features:

- textured surfaces and anti-reflection coatings, which entrap light inside the semi-conductor;
- one or more junctions made of different or differently doped materials, which establish an internal field to separate the electron-hole pairs created by the absorbed photons;
- and metallisation and interconnects to collect the charge at the cell surfaces and conduct it to an external circuit.

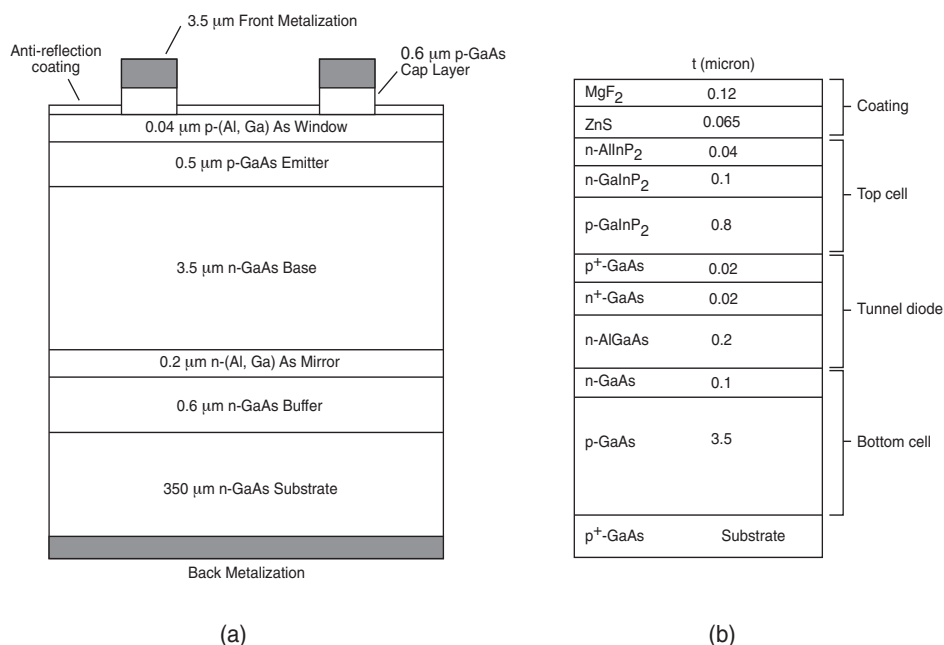
Of the numerous materials and various cell designs possible, only a small number have reached industrial production. Some, such as crystalline GaAs, have been shown to be capable of the highest conversion efficiency of all single junction PV devices, yet have only found a small volume market, mainly in space applications due to their high cost of production. Irrespective of materials and technologies available, the main challenge for PV researchers and the PV industry is to achieve the critical balance between increased conversion efficiency and lower cost of production at the cell level more than at system level. In all commercialised systems so far, the cell cost is the predominant component of the module cost, and the module is the predominant component of the system costs.

Given present technologies, this critical balance between cost and higher efficiency could in principle be achieved by using highly efficient, expensive, small area devices with inexpensive concentrating optics. Alternatively, inefficient but very inexpensive devices able to be produced “by the metre” could be developed. It is therefore interesting to review the present research and industry methods of cell productions and their conversion efficiencies. Using these as benchmarks, the potential for improvements in the efficiencies of each method can be assessed within the foreseeable future.

## Cell designs, production and efficiencies

### High concentration single and multi-junction cells

Single and multi-junction cells made with binary, ternary and even quaternary alloys such as high concentration GaAs, GaSb and InP, are invariably produced on crystalline substrates by advanced epitaxial growth (i.e., following the single crystal structure of the substrate). Up to 20 different layers of materials are used (see Figure 2.24).



**Figure 2.24: Structure of (a) single junction and (b) tandem junction GaAs concentrator PV cells**

The growth processes are carried out in complex molecular beam epitaxy reactors or metal organic vapour phase epitaxy reactors, which construct the layers atom by atom. Limited industrial production of these cells, spurred mostly by space and satellite applications, has shown that efficiencies between 20% and 23% are achievable without optical concentration. The initial crystalline substrate and the production method are both relatively expensive and produce small area, high efficiency devices. Such devices are eminently suited to high concentration applications (100x to 1000x) where expensive cell area can be replaced by single stage and two stage concentrating optics (in area ratios up to and above 300:1). Results have shown that concentrating devices can be produced in the lab with efficiencies between 28% and 32%; these devices are specifically aimed at utility scale electricity generation (Kaminar, et al., 1988; Krut and Glen, 1994; Friedman, et al., 1994).

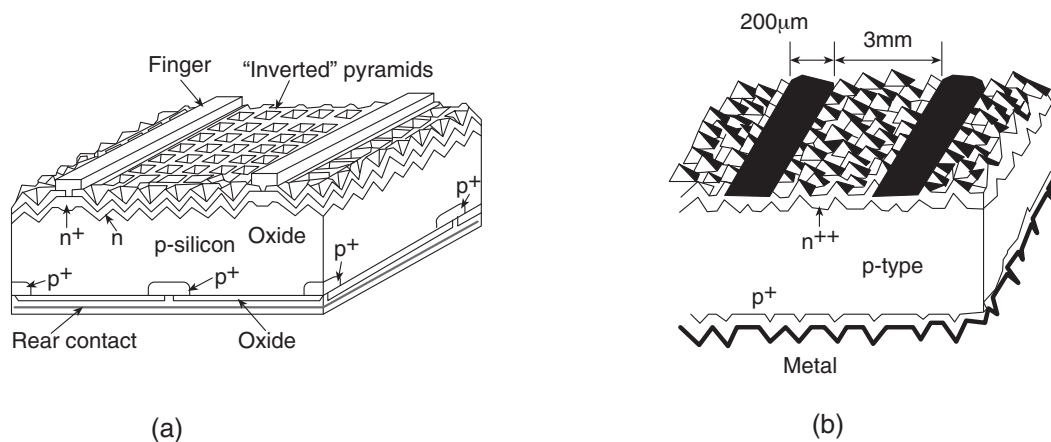
It is speculated that given a long term target cost of electricity of \$0.10/kWh, efficiencies of 35% are required to make this technology viable for terrestrial utility applications (Fraas, 1995). As the theoretical limiting efficiency of single junction devices of this type is below 38%, the target efficiency level is more likely to be achievable using multi-junction devices. These have theoretical efficiencies above 45%. Measured one-off laboratory efficiencies close to 35% have been reached, but for an industrial scale, robust technology has yet to be fully developed.

### Single crystal silicon cells

Historically, the c-Si PV industry has benefited from both R&D and the extensive experience of the larger micro-electronics chip manufacturing industry. The PV industry is not large, so industrial and laboratory cells are fabricated on crystalline silicon wafers, which comply with the more exacting, and more expensive, requirements of the micro-electronics industry. In effect, the PV industry uses the 10% from its more lucrative micro-electronics partner, and pays a premium price of up to \$65/kg for the base material. This may not necessarily be justified in terms of improved cell performance.

The single crystal silicon wafers commonly used for both laboratory and industry cells are made either by pulling from the melt (CZ) or by float zone refining (FZ). The large, single crystal ingots are then cleaned, sawn into 330 $\mu$  wafers, and doped.

High efficiency laboratory cell designs are typified by the passivated emitter, rear locally diffused cell (PERL) produced at the University of New South Wales (see Figure 2.25). It incorporates etched inverted pyramids, anti-reflection coatings, and a full rear contact layer, which reflects the light internally to the cell, improving light capture. Such “light trapping” schemes increase the effective thickness of the silicon cell by an order of magnitude over its actual thickness. Also included in the cell are very narrow, low resistance metallisation (vacuum evaporated titanium and palladium metal over-coated with silver). Lithographic masks were used to produce these narrow, high aspect ratio, low resistance fingers. The rear surface of these cells features “point contact” regions protected by a further oxide layer and the rear metal film. These features, researched and developed over the last 15 years, have enabled laboratory efficiencies of crystalline silicon cells to reach values of 24% (Figure 2.26). Upwards of 15 processing steps are used in the manufacture.



**Figure 2.25: Structure of (a) c-Si PERL photovoltaic laboratory cell and (b) c-Si PV cell produced industrially using screen printing**

By contrast, present commercial c-Si cell production uses screen printing techniques, few or no lithographic steps, and a simple alkaline texture etch to obtain pyramid structures for light coupling. Consequently, commercial cells produced under low-cost mass production conditions have so far reached maximum efficiencies of only 15% (Figures 2.25b and 2.26).

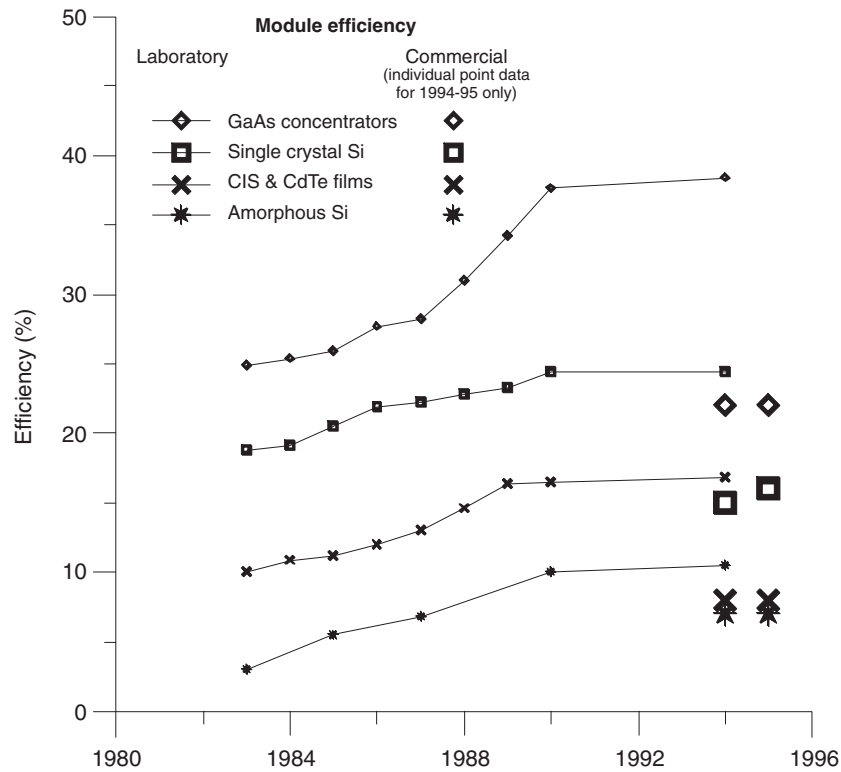
Laboratory cells are expected to continue to increase towards the theoretical 33% efficiency limit. Industrially manufactured cells also have substantial leeway for improvement. They can incorporate a number of features taken from the laboratory cells for very low or nil additional cost. Improved laser or mechanically grooved, buried contacts replace screen printed metallisation and light trapping schemes. These promise both higher light capture and reduction of cell thickness from 330 microns to less than 50 microns.

Buried contact technology has already been licensed to several manufacturers (Green, 1995). The first commercial cells using this technology are providing a 30% improvement in cell and module performance at little or no extra cost, according to the BP Solar company in Spain.

Thinner, (50  $\mu$ ) c-Si cells are presently being developed at the Australian National University, Canberra, and by Siemens Solar, Solarex, and BP Solar. They substantially reduce the amount of c-Si required per device, and hold promise of 18% to 20% efficiencies for industrial cells at module costs of \$3.50/Wp (peak Watt) or less by 2005.

### *Multicrystalline and polycrystalline silicon cells*

The use of multicrystalline silicon as base material for the PV cell capitalises on silicon R&D. “Cast” silicon ingots (or ribbon) can be produced at less cost and in greater volume than c-Si ingots, using slow solidification of molten silicon in graphite, quartz or ceramic crucibles. The ingots are larger, with crystals of a few



**Figure 2.26: Laboratory and industrially achieved conversion efficiencies for the various commercial PV cell technologies**

centimetres, but with poorer material quality and uniformity. They require extra processing steps (hydrogen passivation or heavy phosphorous diffusion) to convert defective regions such as grain boundaries for more efficient current collection. Furthermore, since they are not amenable to anisotropic pyramid etching, the cells have either planar surfaces or use extra processing steps, including laser or mechanical grooving for texturing of the surfaces.

Present p-Si laboratory cells achieve lower efficiencies than the 18% to 20% of c-Si. Based on present quality, an efficiency of 17% is the limit for commercial production using multicrystalline material. This decrease in efficiency is somewhat offset by the lower module costs, making multicrystalline modules nearly as cost effective as c-Si modules for electricity generation.

Compared with expensive crystalline silicon, multicrystalline and polycrystalline silicon use less material, but lower quality is obtained. With newly developed light trapping schemes, cell thicknesses less than 10  $\mu$ m can be seriously considered in silicon. Reduced cell thickness reduces the allowable grain size and therefore the acceptable material quality without a loss in performance. The most challenging aspect of silicon PV research is to combine laser texturing, laser grooving and thin film multilayer technologies. Researchers at the University of New South Wales have speculated that a new multilayer thin film design produced by lower temperature deposition of a small number of thin ( $\sim 2 \mu$ m) layers of polycrystalline silicon on a glass substrate is capable of producing efficiencies of 15% or more. If this is realised, polycrystalline Si cells will be produced in large areas (1 m<sup>2</sup>) or in continuous rolls for well below \$1.50/W<sub>p</sub>, ushering the breakthrough required for solar PV energy to be cheaper than most presently implemented electricity production technologies.

This research is being pursued with the possibility of commercial implementation within the next decade.

#### *Polycrystalline thin film CdTe and CuInSe cells*

Polycrystalline CdTe and CIS based cells offer several advantages for achieving PV system requirements, such as a 30 year life, >15% efficiency, and <\$2/W<sub>p</sub>. They strongly absorb the solar spectrum, requiring only between 3  $\mu$ m and 5  $\mu$ m of material for PV application (as opposed to >100  $\mu$ m of c-Si). These thin film polycrystalline cells can be produced directly on low cost substrates such as glass, plastic or metal foil. CdTe

invariably produces good material irrespective of fabrication technique. Efficiencies of 10% and greater have been obtained with such different techniques as atomic layer epitaxy, chemical spray, evaporation, electro-deposition, sintering and even screen printing!

Laboratory devices made from CdTe have recently achieved ~16% efficiency (Chu et al., 1992). The European project EURO CIS reached 15% for CIS devices (Stolt et al., 1992). Compared with theoretical single junction values of 27% for CdTe and 25% for CIS, multi-junction options can theoretically reach well above 30% efficiencies. A further and substantial advantage of these modules over other thin film systems is that their long term stability in outdoor use has been shown to be outstanding.

Since 1992, solar cell manufacturers such as Siemens Solar, BP Solar, Solar Cells Inc and Golden Photon have established industrial plants to develop manufacturing technologies and have increased module size and efficiencies beyond 0.4 m<sup>2</sup> and 10% respectively. It is expected that within a few years and once processing steps have been optimised, the CdTe and CIS manufacturing technologies will deliver module costs of \$1.60/Wp for 5 MW/year production level dropping to \$0.72/Wp for a 25 MW/year production level.

### *Amorphous silicon, single and multi-junction cells*

Amorphous silicon solar cells have been a commercial reality since the late 1970s, when they were incorporated in personal and household devices (watches, calculators, battery chargers, etc.). They have had a successful twenty year history as a commercial product for electricity generation.

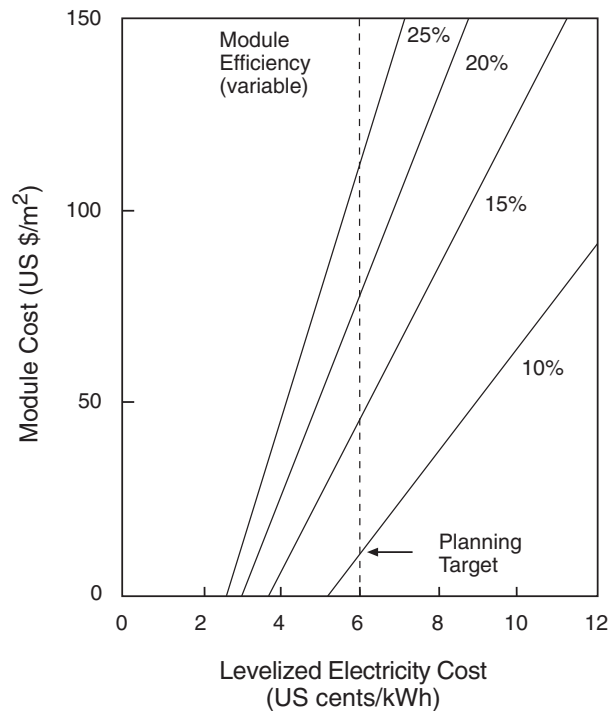
The structure of a-Si cells is very simple and, because of a-Si enhanced absorption, requires 30 to 50 times less material than c-Si cells. The a-Si cell is built up by deposition of a transparent electrode on a substrate of glass, steel or other material; three p, i, and n doped layers of amorphous silicon; and a thin metal film that acts as a conducting electrode. This simple sequence is straightforward to produce on an industrial basis; requires only low temperature processing; and has been deposited mostly by RF-plasma chemical vapour deposition on a variety of solid, transparent or flexible substrates in roll to roll methods implemented industrially in a number of countries. In some implementations, both photomasks and laser patterning have been added to produce connectable submodules of the desired size and area. In addition, see-through modules and ultra light, ultra flexible modules have been produced without changes to the basic industrial process. More recently, integrated modules have been fabricated directly on transparent glass roofing tiles (Matsuoka et al., 1990), roof shingles and windows for incorporation as architectural units into buildings and homes. Industrial modules have routinely achieved initial efficiencies of 6% to 8% which reduce to 5% to 6% or less within the first six months before stabilising. Research aimed at eliminating this “Staebler-Wronski” light degradation has been pursued for some time now with limited success.

Cells have been produced routinely in the laboratory with 10% to 12% efficiencies. However, there is a practical limit in attaining higher efficiencies due to the difficulty in doping amorphous silicon to higher than adequate values. Hence, there appears to be little hope in reaching theoretically predicted efficiencies of >15% from single junction devices. Most a-Si research and some commercial developments are presently concentrating on production of two and three junction devices with a-Si:H and its alloys in the expectation that the very low cost of production will make this latter conversion technology (if it can reach 12% efficiency) the technology of choice for remote area, distributed and even utility scale electricity production within the next ten years.

### *Summary*

Present reasonably priced commercial collectors have a cell conversion efficiency performance of 9% to 12%. Efficiency gains are possible both at the laboratory research and industry levels. These efficiency gains translate directly into cost savings: the higher the efficiency the lower the cell production cost and hence the higher the amount available for the costs of modules and balance of the system.

This is illustrated in Figure 2.27, which shows an example of the “available module cost” as a function of levelised energy cost for a number of efficiency values; the higher efficiencies lead to higher possible module costs. Hence for all the technologies presently realised, except perhaps amorphous silicon with module efficiencies <10%, the target cost for the most stringent application, that of central power generation, appears achievable or at least not precluded by efficiency considerations alone. Nonetheless, up to this day, silicon has been the almost exclusive workhorse of the PV industry worldwide.



**Figure 2.27: Calculated module cost as a function of target levelised cost of electricity (COE) for various values of module efficiency (\$1US = \$NZ1.67)**

## System elements

### Modules

Irrespective of cell technology, the basic PV product sold by the industry is the PV module. This is the package that makes solar electricity generation with a number of connected cells into a safe, durable, reliable structure, which will achieve the desired lifetime of 30 years even when exposed to environmental stresses.

Present typical module assemblies include a low iron glass for the front surface, ethylene vinyl acetate films above and below the solar cells, and a back cover film of polyvinyl fluoride. This sandwich, with the cells already interconnected and soldered together, is laminated under vacuum at temperatures of  $\sim 150^{\circ}\text{C}$ . The curing process encapsulates the cells, protecting them from moisture ingress. Junction boxes are then added and frames rubber sealed around the edges, completing the module fabrication process.

The basic cell produces around 0.5V and collector modules are manufactured with peak outputs of up to 20V and usually available in standard 6V or 12V DC outputs. They can be interconnected in series to generate higher voltages or paralleled to provide typical currents of two to three amps. However, industry rating of modules is almost universally by peak watts output, which is specified for standard test conditions (1000W/m<sup>2</sup> irradiance, 25°C, and 1m/sec windspeed). Individual panels can be purchased with peak power outputs in the range of 1W to 100W.

### Battery and charge controller

Stand alone systems (see section 6.2) normally require battery storage. This may be part of an existing installation or may need to be added with the introduction of PV. Simple systems merely connect the nominal 12V PV panel directly (through a protective device) to the lead acid, deep cycle battery; however, matching is not ideal. More energy can be extracted from the PV system, and the battery is better protected, if a power electronic charge controller is interposed between the two components.

### Inverter and power conditioning unit

Where AC power is required, the system must have a power electronic converter to invert the DC output from



the PV cells to AC at the correct voltage. If network connected, this equipment usually controls the safety disconnect to avoid islanding (where individual PV collectors or clusters continue to generate electricity during removal of the AC system). It also controls restarting when the network or solar input is restored. As PV cell prices drop, this component will assume a higher portion of the system cost. Modern units are automatic in operation and require no maintenance. Wide load band efficiency is very important since the PV panels are not generating their full capacity most of the time. Many inverters currently on the market are not very good in this regard, with typical operational efficiencies averaging less than 80%. Earlier generation units generated square wave type outputs, and proved to be a cheap and reliable solution for stand alone applications. However, more sophisticated equipment is essential for network connection. These are available in the form of sine wave inverters, which generate a waveform essentially identical to the mains system supply. These inverters can also be designed to provide reactive current if required to stabilise the end of line voltage, or reduce line VA and losses.

### ***Metering and safety disconnect***

Where a small PV system generates surplus electricity, this may be sold to an energy company. Minimum additional requirements in this case are upstream metering and an electrical safety disconnect system.

### ***Support structures, tracking systems***

The flat-plate solar modules are often tilted at an angle for greater capture of the available solar energy. For this they require sturdy support structures that can withstand a wide range of weather conditions and wind loadings. In concentrator systems, tracking motors and systems are used to enable the panel to follow the sun in one or two axes. In these systems, tracking accuracy has a direct influence on the system output, but additional cost is involved.

### ***Types of systems and their applications***

The above elements are used in a variety of combinations depending on the application:

- stand alone DC use — panels, a charge controller and batteries form a typical system;
- larger DC/AC applications — an inverter is included;
- grid connected systems — battery backup and controller are optional; and
- large scale systems with grid connection — additional advanced reactive power conditioning, metering and safety disconnects are an integral part of the system.

In most of their manifestations, PV power systems have versatile size and power outputs, from microwatts for watches to megawatts for central grid connected power stations. The possible markets for these systems are diverse, often with quite different and opposing requirements. The main applications can be divided into three or four broad sectors, namely consumer products, industry applications, remote area electricity services, and grid connected systems.

### ***Consumer products***

This application has proved to be the first substantial market for PVs, especially a-Si modules. Included here are small power supplies for personal items (calculators, watches, toys), domestic power supplies (remote houses, holiday homes, caravans, mobile homes, boats), and individual supplies for novelty products (home security, garden lighting, car sunroofs, fans, and battery chargers). The cost of electricity in these applications is quite irrelevant and quite high on a dollar per watt basis (>\$40/Wp), however the PV solution is very successful as it displaces even higher cost options (mercury batteries) or provides a more elegant alternative, such as a built-in, virtually maintenance free power supply on mobile homes, caravans, and boats.

Although the usual systems are quite small, providing typically only milliwatts at up to 12V, the number of items is sufficiently large to support an annual 27 MWp global market at the present time with projected growth to 30-50 MWp by the year 2000.

### *Industrial applications*

There are a number of applications where PV systems are sold to a service industry that then uses these for its own purposes, in its products or services. Foremost in this area are “professional systems” provided by companies active in the communication industry and the cathodic protection industry. In New Zealand, both communications and cathodic protection companies have used PV supplies for maintaining radio transmitters or establishing cathodic protection for gas pipelines. In both cases, the remoteness of the site from the grid has been a major consideration. This market is differentiated from other applications in that reliability of supply is essential “every minute of the day” and loss-of-load probability is reduced to below 0.01%.

This application is relatively small at present in New Zealand compared to overseas, where it is expected to reach 100 to 180 MWp by the year 2000.

### *Remote area power supply (RAPS) services*

This includes applications of small to medium scale PV technology, ranging between hundreds of watts for individual dwellings to community supplied services in regions away from the main distribution grid (see section 6.2). This is thought to be a pivotal growth area for the PV industry in the coming decade in both industrialised and developing countries. The range of services includes:

- water pumping;
- water treatment;
- electric supply for small industry, domestic, medical and institutional uses (schools, clinics, small shops, farms); and
- communication links, both local and long distance via telephone, television and radio.

Typical of this category of applications is the proposed displacement of diesel fuel for power generation in remote towns, mining camps and homesteads in Australia (Australian National University, 1995). PV systems in this application are already substantially more competitive than other fuel options, such as diesel generation at \$0.50/kWh. This, and similar power system requirements in the developing countries of the Asian/Pacific rim (India, China, Pakistan, Indonesia and Malaysia), are capable of providing a very profitable multibillion dollar stepping-stone market for the next ten years. This would enable the PV industry to upscale, thereby reaching cost competitiveness in large scale applications through economies of scale.

Estimates of this market are not straightforward but range upwards of 300 MWp by the year 2000.

### *Grid connected systems*

Apart from full scale central PV stations feeding power to the grid, there are two other grid connected applications close to being mature, cost effective opportunities for this renewable energy. These are embedded generation and distributed generation systems.

Embedded generation PV systems can provide a cost effective solution for a utility distribution network that experiences either overloads or degraded power quality at critical points (Shugar, 1990). The present solution to degraded power quality or overloads is to upgrade the line, associated switch gear and transformers. In certain cases, it is more cost effective to install PV plants at the critical points rather than undertake expensive upgrades. In such cases, a 10 kW to 1 MW embedded PV generation, costing up to twice conventional plant, can sometimes still provide a cost effective solution (Iannuchi and Shugar, 1991). This solution is also likely to be very attractive in developing countries where electricity demand consistently outstrips supply, leading to overloads, disruptive brownouts and blackouts. A very successful illustration of this embedded application can be found in the Kalbarri 20 kW PV system in Western Australia.

Distributed generation involves the supply of electricity to individual buildings from PV systems attached to the buildings. The buildings are also grid connected and therefore take electricity from the grid when demand exceeds the PV output and feed it back to the grid when it is unused by the building. In this application, which is being trialled extensively in several countries, including Germany, Switzerland, the UK and Japan, the PV installation can be either on the roof, therefore not incurring area related costs, or be part of the architectural

units of the building: facade cladding in high latitudes or roof tiles in lower latitudes. This can obviate some of the building construction costs (Hestnes, 1995).

Large, land based central PV stations have been developed, tested and operated for a number of years. Their sizes range from tens of kilowatts to 1 MW, at Toledo, Spain. A useful summary of results of these large scale systems has been gained through the Photovoltaics for Utility Scale Applications programme in the USA, where in 1993 a total of 2500 MWh of electricity was produced from a variety of complete PV systems. The high reliability of PV systems has been confirmed; the main areas for future improvements are the inverter and control electronics. It is now evident that PV solar power plants can operate with very little maintenance indeed compared to other electricity generation technologies.

### *Limits of applications and synergies*

Photovoltaic power systems have been used extensively both on earth and in space, outdoors as well as indoors, in full sun and in the shade, in the tropics and in Antarctica. Their reliability and very low operational maintenance requirements are why they are the preferred option in isolated, critical supply situations. The main limitation in the application of PV is the short term variation in the solar resource on a minute, hourly and daily basis (as will be seen later, longer term variations are small). This can be mitigated to a large extent in a number of ways:

- storage of surplus output in batteries;
- smaller scale generation in a number of geographically and climatically different sites; and
- the use of PV systems for applications where the PV output is well matched, on an hourly basis say, to the demand (e.g., air conditioning and ventilation of commercial and industrial buildings).

Synergies with other renewable and non-renewable energy supplies are technically feasible. Combinations of PV-wind and PV-diesel generators have been used in a variety of situations. Invariably, adequately sized PV provides the bulk of the power, other sources functioning as rarely used backups. A very interesting option to investigate, especially for New Zealand, would be the use of PV with hydro storage, as there would appear to be complementary seasonal variabilities between these two sources of supply. Hydro lakes are fed mostly by snow thaw in spring whereas the highest output of PV is in the late summer (Gale, 1996).

The present and projected world market for all PV modules between the years 1982 and 2005 is shown in Figure 2.28. The future shipped wattage is expected to increase from the current 160 MWp to over 370 MWp by 2006 if the present trend for mostly stand alone applications is replaced by a balance between stand alone and grid connected applications. This would, of course, require substantial penetration of PV into the grid connected market, which is the area where most state supported and funded overseas R&D has concentrated in the last few years. A brief overview of these R&D projects is presented in Annex 2.1.

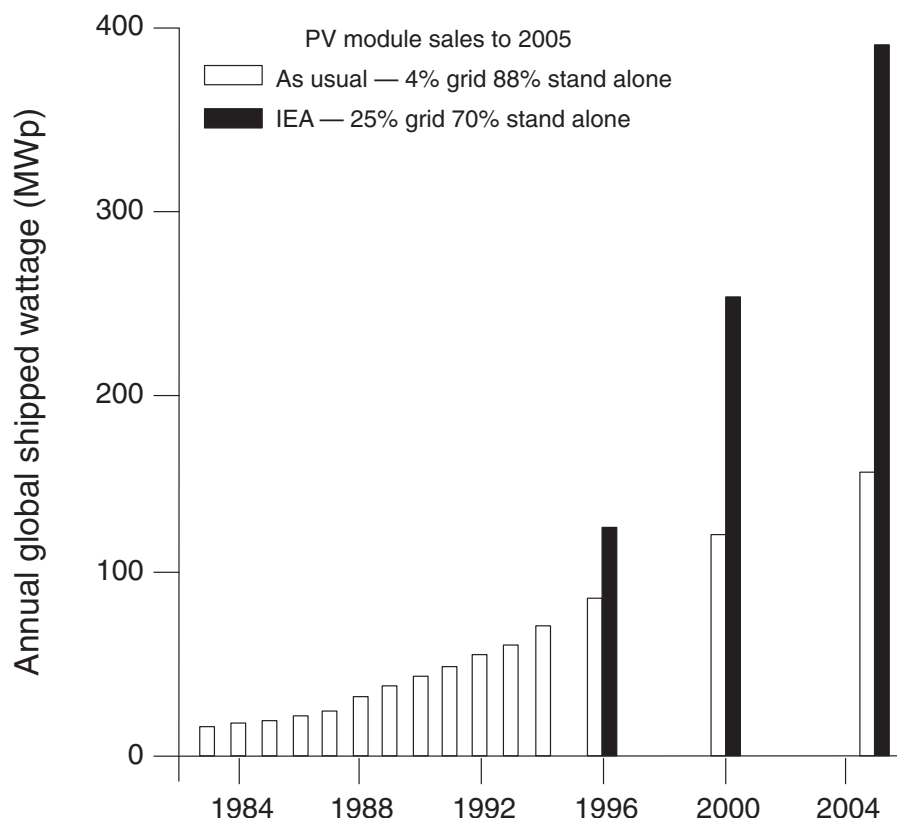
## **2.4.2 New Zealand Experience**

### ***Present commercial activities***

Industry estimates of the total installed PV capacity in New Zealand is around 200 kW, with approximately 75 kW installed in the last three years alone. A yearly rate of increase of over 15% for the next few years is anticipated. This recent increase has been in part due to a very active Telecom remote site market. A substantial number of the installations have been in place for several years, maritime beacons having been operated satisfactorily for upwards of twelve years around New Zealand's coastline and harbours with very little servicing.

Interestingly, sales in New Zealand have encompassed all three silicon based technologies: monocrystalline, polycrystalline and amorphous modules. The first two provide the bulk of sales, offering a wider range of module sizes and longer life.

Most electricity supply companies have shown keen interest in the technology, some installing small stand alone demonstration systems to gauge their potential and to assess the public's interest in the technology.



**Figure 2.28: Actual and projected (beyond 1994) global PV module sales to the year 2005**

These systems vary from single panels up to the Energy Direct 0.5 kW installation, which includes charge controllers, batteries, inverters and regulators for feeding power into lights, fridges, and home appliances. Other suppliers are actively participating in limited studies of the long term performance of a small PV system for urban electricity generation being undertaken by IRL.

Several New Zealand manufacturers have either included PV modules in their product or designed products to be specifically powered by PV systems. Examples include an internationally successful navigation beacon that can be fully powered by photovoltaic panels and backup (Cook, 1996). Until recently, the main New Zealand users of photovoltaics have been the New Zealand Maritime Safety Authority and harbour companies. Of the 860 light beacons operating, up to two-thirds have been converted to PV with rarely needed diesel backup, saving hundreds of thousands of dollars a year in diesel costs, maintenance and transport costs (Belt, 1996).

Gallagher, PEL and Speedright, New Zealand's leading manufacturers and exporters of electrical fence equipment, offer a range of PV battery fence units that are extensively used by many farmers. Remote monitoring stations, instrument packages and houses at remote sites such as Great Barrier and Waiheke Islands are often equipped with either solar PV or PV-wind hybrid systems. These have either replaced full diesel systems or in some cases substituted for cabled electricity, as on Teriteri Island, because they proved a more cost effective replacement solution. More recently, PV systems have been used by Telecom to power individual sites and relay stations for the New Zealand Police, the New Zealand Meteorological Service and NIWA for remote telemetry.

It appears therefore that the main activities in New Zealand are with the original equipment manufacturers (OEM) and remote area power supply systems (RAPS). Early experience with crystalline systems was satisfactory and cost effective, however with amorphous systems the efficiency deterioration experienced in the field was sufficiently serious to cause recall of installed modules. The total yearly value of these two applications (OEM and RAPS) has been calculated at between \$0.45M and \$0.5M in 1992, and is expected to be ~\$0.7M in 1996.

### **Potential commercial developments by 2005**

RAPS will continue to grow in New Zealand at about 15% per annum in already established applications such as telecom sites, island power supplies and remote telemetry sites. Other applications such as electric fence supplies for local and export use are likely to experience a sizeable increase as the advantages of PV are realised.

Optimistically, a number of new activities trialled in countries overseas but not yet adopted in New Zealand could occur.

- The use of PV by companies providing industrial services in New Zealand as well as to Australia, the South Pacific and beyond, such as companies laying gas pipelines incorporating PVs for cathode protection in their designs.
- Small community supplied services in regions away from the grid. In view of the extent of the grid in New Zealand, this is likely to be limited until costs of PV systems become less than the costs of setting up transformers, rectifiers and line extensions. Currently, the cost of new power lines for domestic supply is around \$20,000/km, so potential users may no longer be “remote”.
- A demonstration of distributed generation in one of the main cities in a commercial/industrial or domestic building. This is expected to occur by the year 2000 or earlier and would lead to greater understanding and awareness of the technology and its uses in a city environment (Cope, 1996).
- Beyond the demonstration stages, interest from energy suppliers and providers will likely give impetus to grid connected generation for larger industrial buildings and spaces. This would be due less to shortage of electricity than to the cost of cabling from city limits through to its place of use in the city.
- There could be a small assembly and manufacturing industry established soon to service a future market likely to be of the order of several megawatts per year in size.
- The likelihood of centralised solar PV power plants in the sunnier regions of New Zealand for local use or end of grid generation is also high and could be envisaged in the present wholesale electricity market environment.

### **2.4.3 Current Energy Resource and Potential**

The “Sun + Sky” is a variable energy source dependent on many parameters. It varies:

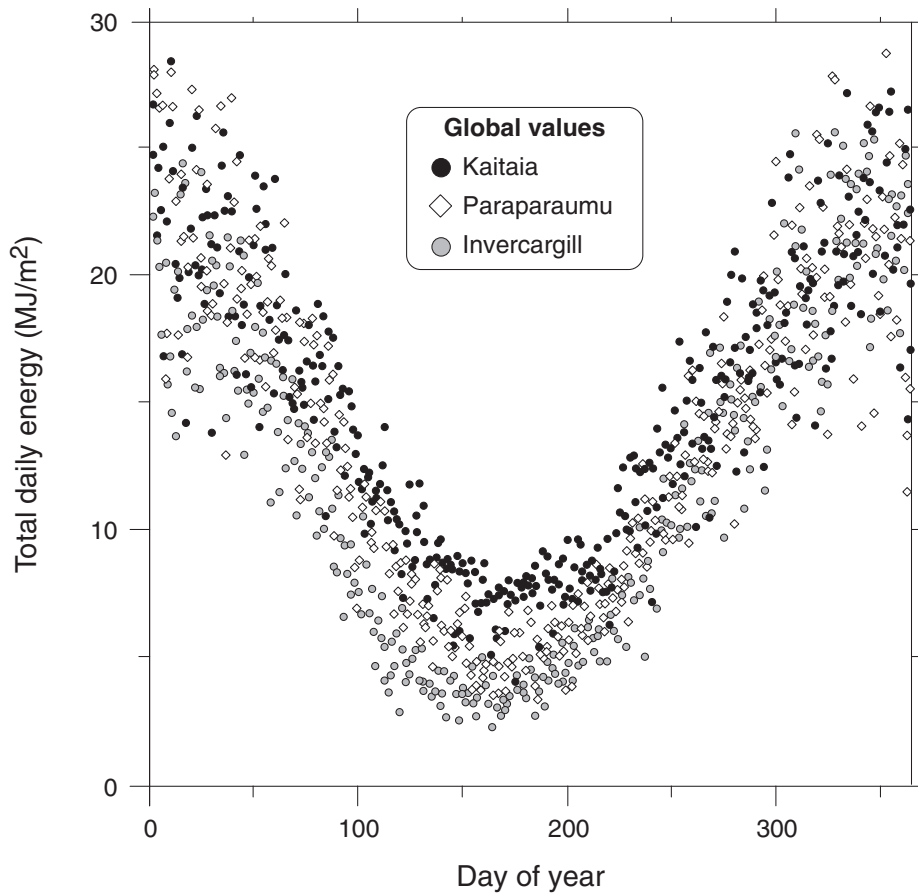
- in time — during the day, and over the year;
- in space — across the sky dome and depending on the weather patterns; and
- in its spectral content — from the ultraviolet through to near infrared wavelengths ( $>2 \mu\text{m}$ ).

Any attempt at using this plentiful energy source must take not only its magnitude but also the detailed variability of this magnitude into consideration.

The magnitude of the solar resource is staggering, as outlined in Section 2.1. Every horizontal square metre of New Zealand land receives between 4.7 GJ and 6.5 GJ of solar energy input per year, equivalent to around 1500 kWh/m<sup>2</sup> per year. A large house with a total electricity consumption of 15,000 kWh per year would require at 10% efficiency a horizontal collection area of 100 m<sup>2</sup> together with an efficient storage battery to meet all its power needs.

The geographic and temporal variability of the solar resource is significant. Geographic variations are illustrated in Figure 2.29, which shows the total daily energy on a horizontal surface at three sites across New Zealand throughout a typical year. This value varies from 23 ( $\pm 5$ ) MJ/m<sup>2</sup> in summer to 6 ( $\pm 3$ ) MJ/m<sup>2</sup> in winter.

There is a clear trend in the total daily energy towards generally higher values at the more northern latitude of Kaitia, but this does not preclude stronger counter variations due to local micro-climates (e.g., Hawkes Bay and Nelson). Therefore, the location of PV stations plays a significant role in their viability.



**Figure 2.29: Scatter plot of total daily energy received on a horizontal surface as a function of the day of year for three sites spanning New Zealand latitudes**

Temporal variations of daily energy, indicated in Figure 2.29, are typically greater than 30% throughout the year. The integrated total energy on a horizontal surface at any one site is relatively constant from year to year and even from month to month. For shorter time periods in the order of hours or minutes, typical variations are much larger. Such values are shown in Figure 2.30, where the minute by minute global horizontal, direct and diffuse irradiances throughout the day, and for December, March and June are reported for the Paraparaumu site. This variability is usually reduced if the collector panel is tilted towards north or if a concentrating tracking system is used. All the same, this highlights the importance, especially for PV systems, of carrying out short time step (minute intervals), dynamic simulations, or actual field trials to determine the expected output from a given system.

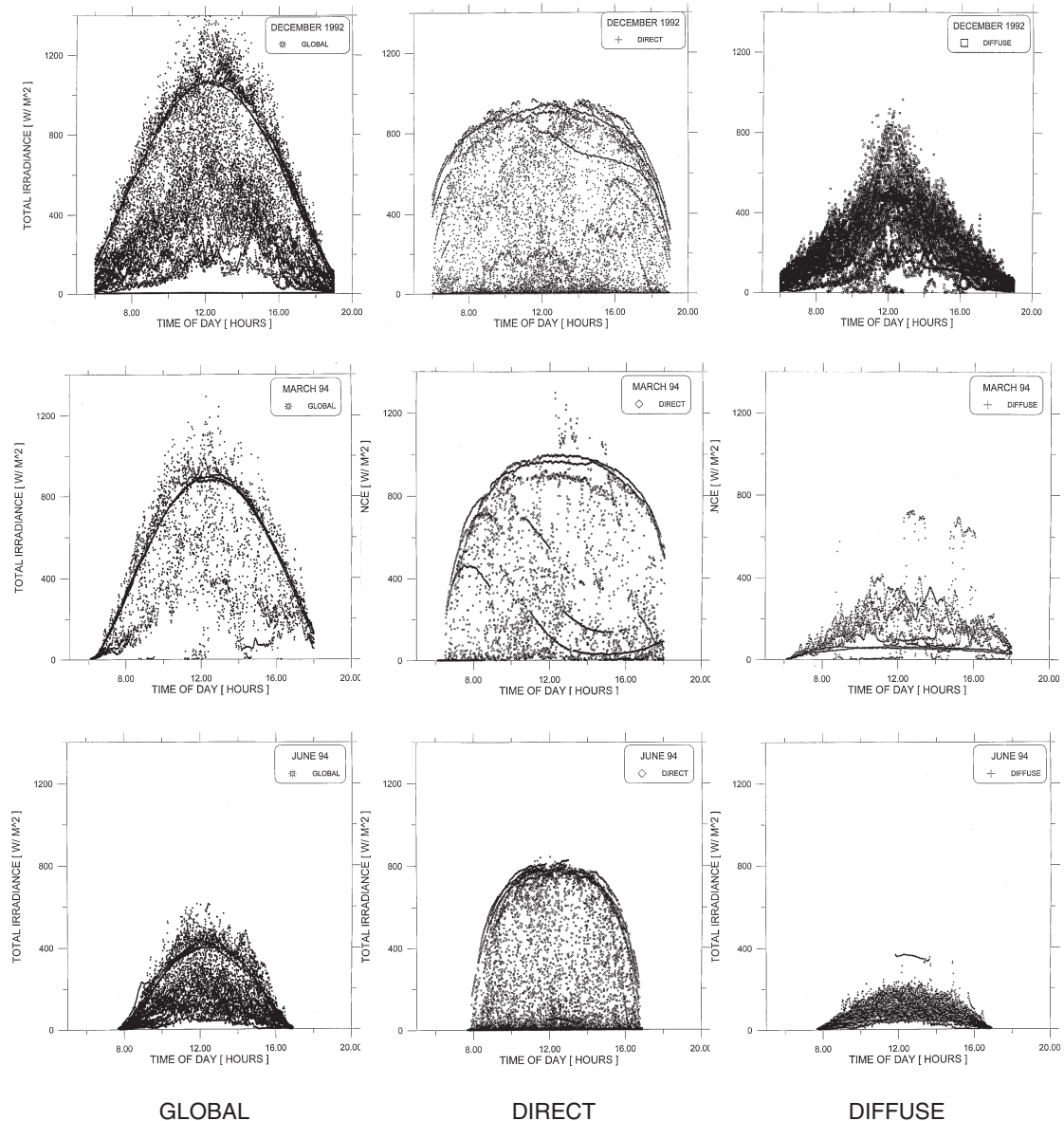
Such work has been initiated for only a few sites in New Zealand so far by IRL in their Daylight and Solar Availability research programme and their PV Monitoring programme. Preliminary results for a nominal 300 Wp, network connected rooftop site at IRL, Christchurch are presented in Figure 2.31, where the hourly insolation and hourly PV output are shown. Figure 2.32 summarises the site specific relationships obtained for daily, monthly and yearly insolation and PV output. Such data is vital to enable accurate predictions of the PV potential of New Zealand sites, but is still lacking.

For an estimate of the expected yearly output from a PV panel, the values in Figure 2.29 multiplied by the panel efficiency provide a good first approximation. The seasonal variability for panels tilted at different angles or using concentrating optics require dynamic simulations based on typical radiation years representative of the site in question. These are presently being developed at IRL and sponsored by ECNZ.

#### **2.4.4 Environmental and Social Aspects**

PV manufacture sometimes entails the use of chemicals and processes that are toxic (cadmium, selenium,





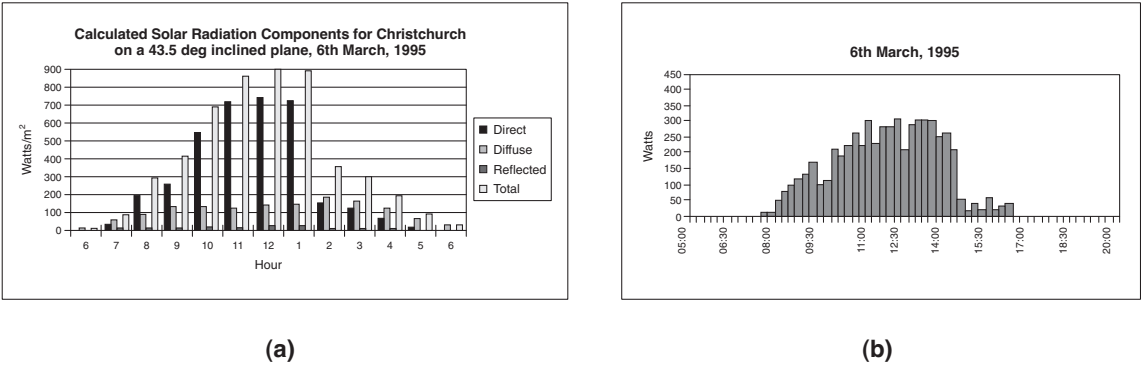
**Figure 2.30: Plots of global, direct and diffuse irradiances as a function of time of day for three different months of the year at Paraparaumu**

arsenic) or may cause acid burns. However, extensive experience with these materials is available in the industry. Risk management methods and regulations are extensive to cope with the use of these materials. Waste disposal must be given due consideration. Module recycling and disposal after their useful lifetime in ways acceptable to environmental health and safety laws is presently the subject of investigation but appears straightforward (Moskowitz, et al., 1995). Methods and procedures for the decommissioning of larger plants would have to be established. Photovoltaics produce both DC and AC voltages and currents similar to those in numerous mains electricity substations.

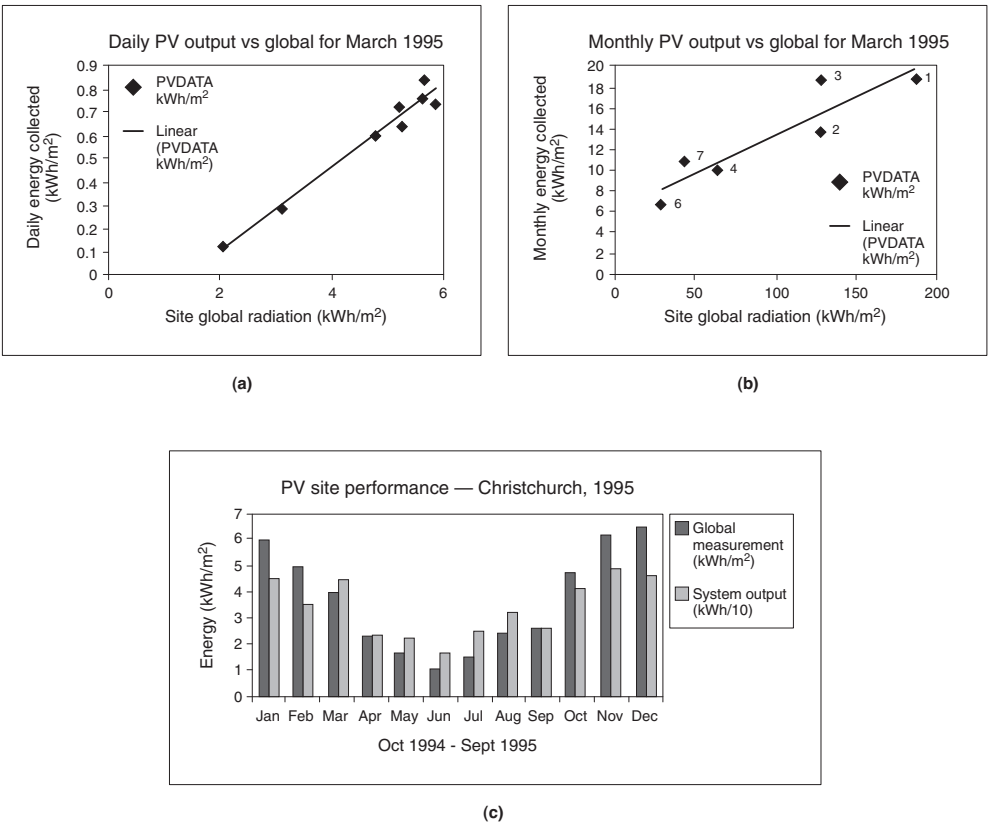
Attention to good design can minimise any visual impact. This may be more of an issue in stand-alone systems and larger applications (depending on the site and scale), rather than systems integrated into the building design. In architectural use, it can arguably add to the aesthetics of buildings. In stand alone and distributed applications, collectors usually occupy unused land area and may provide useful covered space (e.g., covered parking areas). In large applications, the requirement for sizeable land areas due to the low irradiance of the solar source would require debate and detailed reference to the planning process.

In stand alone applications, PV systems incorporate storage batteries. The environmental implications from





**Figure 2.31: (a) calculated solar irradiance components on a surface tilted at the latitude angle at Christchurch as a function of time of day and (b) corresponding measured PV panel output for the same day**



**Figure 2.32: Daily (a), monthly (b), and yearly (c) integrated PV output as a function of integrated global irradiance received on a horizontal surface in Christchurch**

using lead-acid or newer technologies needs to be considered. Recent design improvements in lead-acid batteries have reduced the amount of materials used in their manufacture, increased their life, and enhanced recycling opportunities.

### 2.4.5 Economics

Traditional engineering-oriented revenue based procedures to identify least cost options have recently been discredited and even blamed for loss of competitiveness by the US manufacturing industry. This methodology was developed in the context of active, expense-intensive technologies whose costs were readily “matched” to output. The newer technologies, especially solar technologies, are quite different. They are frequently

passive and capital intensive and their additional lifetime costs and charges are trivial compared to the lifetime benefits produced (e.g., reliability of supply, good customer PR, reduced overheads, reduced line losses, improved quality of supply, and environmental benefits (Awerbuch, 1993)).

In a series of papers reported by Awerbuch (1995), it was argued that as in financial portfolio investments where a range of risk-return options compete, the return from energy technologies such as PV could be assessed more accurately vis-à-vis conventional fossil generation using finance oriented procedures. This methodology seems better able to account for risk, technological progress, and possible environmental outcomes. It would appear that the case for PV improves by up to 50% using these methodologies.

### *Cost methodology*

In the following cost estimates based on traditional methods, several assumptions were made as to the relationships between relevant variables.

- The cost of PV modules (\$/m<sup>2</sup>) was calculated from cell manufacturing costs (\$/W<sub>p</sub>) and cell efficiency (%) given standard test conditions (1000W/m<sup>2</sup>, 25°C and 1m/s windspeed). Typical retail prices in New Zealand range from \$10-15/W<sub>p</sub>.
- Total PV plant costs include module costs (\$/m<sup>2</sup>), balance of system (BOS) cost per square metre for equipment such as support structures, trackers and electrical cables, and BOS cost per kW for equipment such as power conditioning, controls, switches and transformers.
- Operating and maintenance costs were very small, about \$0.009/kWh.

Area related BOS costs	\$47.70/m <sup>2</sup>
Power related BOS costs	\$390/kW
Indirect costs (including RMA, etc.)	0.225 (22.5%)
Capacity factor	26.5%
Fixed charge rate	0.100 (10%)
System losses	0.20 (20%)

### *Present and future supply*

The present price per peak watt at which various commercial technologies can be obtained is presented in the third column of Table 2.1. The corresponding conversion efficiency is the adjacent figure in column two. The timing of commercialisation, the price per W<sub>p</sub> and expected efficiency for other technologies under development are also shown in the table. GaAs technology delivering 30% efficiency, for example, is expected to be commercial by the year 2010 and available then for between \$1.35 and \$2.20 per W<sub>p</sub>. Note that a cheap, moderate efficiency version of single crystal Si technology (type ii) is expected by the year 2010. The date of commercialisation of multilayer Si is uncertain, but should occur sometime between the year 2000 and 2010.

The price shown for single crystal modules at 15% efficiency is that already offered to distributors or large purchasers in 1995. Given a 15% efficiency, the price per peak watt converts into a module cost in New Zealand dollars of about \$1000/m<sup>2</sup>. To calculate the cost of electricity for the most stringent situation, that of independent power generation, the module cost is combined with BOS costs, and levelled over the lifetime of the plant and expressed in terms of the likely energy production, considering present and future cell efficiencies. The resulting \$NZ/kWh figure is shown in the first row, last column of Table 2.1. The same method is used to calculate the other cost of electricity (COE) figures in the last column. For example, amorphous silicon technology at 12% efficiency is expected to be commercial by 2010 and to yield a COE of \$0.14 to \$0.17 per kWh.

It would appear that most existing technologies as well as projected ones (p-CIS, p-Cd-Te, multi-layer p-Si) are capable of reaching the efficiencies assumed in Table 2.1. They will invariably require a three- to four-fold decrease in cost/price per peak watt to compete with other energy sources. However, this is thought likely

Technology		Efficiency	1995 Cost/Price \$/Wp	2000 Cost/Price \$/Wp	2010 Cost/Price \$/Wp	Cost of Electricity \$/kWh
Single crystal Si	i	15%	6.15-7.10	2.50-4.20	2.00-3.30	0.42-0.48
	i	18%				0.19-0.29
	i	22%				0.16-0.24
	ii	18%				0.14
Concentrators/GaAs		22%	6.70	2.00-3.30	1.35-2.20	0.46
		25%				0.16-0.24
		30%				0.12-0.17
Amorphous Si (similar values hold for p-CdTe, p-CIS projected molecules)		6%	5.00-6.00	2.00-3.30	1.25-2.10	0.40-0.65
		9%				0.19-0.28
		12%				0.14-0.17
Multi-layer Si		18%		1.65	→ ?	0.11

**Table 2.1: Comparative costs in \$/NZ of electricity generated from current PV technologies**

to occur once a sufficiently large market enables the adoption of substantially upscaled production, which is thought to be possible by the year 2005. Interestingly, the multi-layer-Si technology is projected to reach the lowest levelised cost of electricity. However, despite very promising research results (Zheng, et al., 1995), this technology is as yet only at the laboratory stage.

It is clear from the COE in Table 2.1 that PV technology is and has been cost effective for a long time in specific applications such as original equipment manufacture and markets for remote area power supply systems (RAPS). The question is no longer whether PV technology will become cost effective but rather which technology will reach the next envisaged application for distributed generation or ultimately for central power generation.

At the reduced module costs envisaged, the BOS costs become a significant proportion of total cost. This is already having a direct effect on the validity of R&D in power electronics and storage technologies used in solar energy systems.

### *Cost sensitivity analysis*

The sensitivity of COE to various component costs is shown in Figure 2.33. The baseline assumptions were arbitrarily taken to be as above, which gave a COE of \$0.11/kWh. The component costs were allowed to individually range from the highest present cost to the lowest target realistically expected to be achieved by 2005. For example, BOS power was varied from \$500/kW (2.2 x baseline) to \$150/kW (0.75 x baseline).

The main conclusions were that insolation levels, cell efficiency, module cost and fixed charge rate had the major effects on the electricity costs. Higher cell efficiency can palliate for low insolation. Module costs, currently three times those needed to yield the baseline value, have good potential to be reduced and hence lower the COE. Once the base value is actually attained, there seems little room for further useful decreases. Interestingly, the fixed charge interest rate applied to the total capital investment has a significant leverage effect on achieving the baseline cost. Ultimately, only cell efficiency is capable of delivering, on its own and by 2005, a COE lower than 8c/kWh.

It must be noted that the graph shows the effects of changes in only one component cost at a time. Realistically, cost reductions and parameter improvements occur concurrently, thus having a cumulative effect on the ultimate COE and the timespan for reaching it.

In the future, if a major implementation of domestic grid connected PV systems was made of modules around 3 kWp per dwelling, the capital cost might reduce to \$5-6/Wp, giving a domestic retail COE price of around 20c/kWh. By comparison, the Clyde dam project cost around \$4/Wp. In the longer term, if the PV system capital cost could be reduced to \$2/Wp, the COE will fall to 10-12c/kWh and transmission load stresses will be simultaneously reduced.

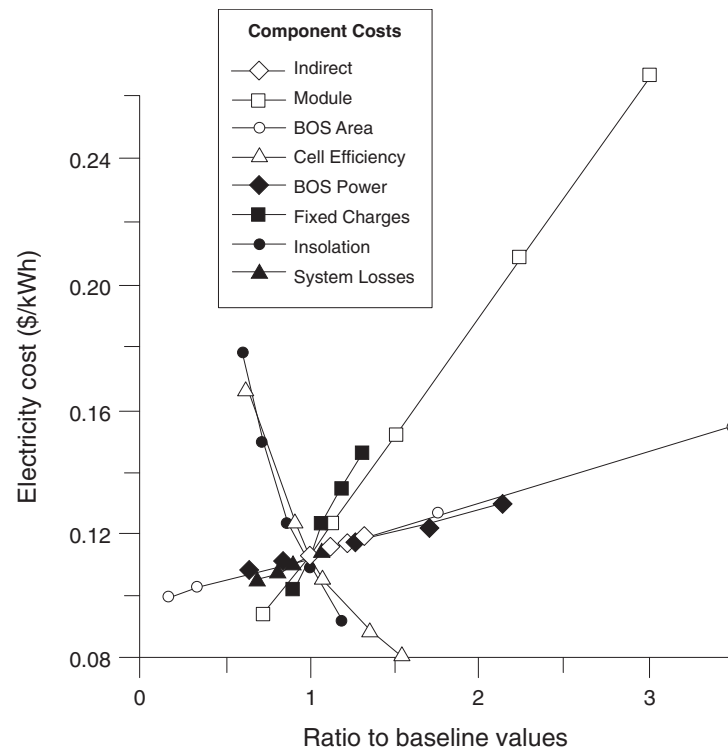


Figure 2.33: Sensitivity plot of cost of electricity (COE) as a function of realistic variations in the component costs predicted to occur by 2005

## 2.4.6 Constraints and Opportunities

### Constraints

The main constraints for PV implementation worldwide are the lack of a substantial world market, which would allow in the future considerable industrial upscaling to  $\geq 100$  MWp per year of this near cost effective technology. The main consequence of this will be the continuing high cost of PV modules and resulting COE. An ancillary factor is the cost accounting methodology itself, which takes no account of distinct advantages and downstream gains from using these renewable energy sources.

In relation to New Zealand, a further constraint is that resource limits are unknown. Therefore, potential contributions of PV and the extent of matching power generated to the present and future electricity requirements are unknown and unexplored.

### Opportunities

The main advantages of solar conversion systems, and PV in particular, are their widespread acceptance as a clean, renewable, benign source of energy which requires very little maintenance. They are symbols of clean, green energy conversion technology. This high profile means that PV produced electricity is eminently sellable and would attract a premium (*Energy Wise News*, 1996). Adding PV systems to our exports would add to New Zealand's recognised green image.

In a newly deregulated electricity market, if costs were to be accurately apportioned between traditional and new generation technologies, these costs should reflect real advantages sought by New Zealand society as a whole, such as the least overall cost (including pollution costs), long term sustainability and reduced supply risks.

In view of the anticipated increase in the use of PV worldwide, there is an opportunity for New Zealand to undertake a number of demonstration projects to ascertain the usefulness of PV generation and to confirm the types of applications likely to be suitable for PV electricity. The anticipated carbon tax levies could be used to support such demonstration programmes (Sinclair, 1996).

More pragmatically, and considering PV generating systems as a whole, there is an opportunity to develop a local assembly industry based on power electronics research presently being undertaken in New Zealand. This would address the gaps existing in present PV balances of system hardware. The value of this research has been confirmed by the success of New Zealand's bid to be a joint partner in an Australian Co-operative Research Centre for renewable energy and greenhouse gas mitigation.

Residential use of PV could be one of the key future growth areas. At present, PV system establishment costs are not being significantly offset against grid connection costs. Nevertheless, for various reasons, more people are selecting private PV based systems as a viable alternative to mains power. The costs of such installations is becoming more competitive as the economic and environmental disadvantages of mains electricity deters more and more users. To encourage this trend, the "Fraunhofer-Gesellschaft" solar house project in Germany (see Section 2.3) was undertaken to make the public more aware of viable energy alternatives. A similar demonstration is required in New Zealand.

### **2.4.7 Further Research**

The pre-eminence of Australian researchers in silicon based photovoltaic conversion technology has provided an opportunity for New Zealanders to collaborate in the latest research. This was done with the aim of identifying and adopting the most suitable results to New Zealand's conditions in the near term. In some cases, such as for system power electronics, New Zealand researchers continue to lead joint Australian/New Zealand efforts. Both these collaborations are of direct benefit to New Zealand in establishing a base of knowledge on the various PV options and enabling the adaptation and rapid uptake of the most appropriate local solutions.

More directly, effort is needed to complete a New Zealand-wide solar PV resource assessment and analysis in order to identify suitable sites and applications for PV generation. New questions posed by the addition of these new technologies to existing generation and distribution grids will need to be answered. New control strategies will need to be developed to better understand the effects of multiple, temporally variable and electrical supplies on the electricity generation system and transportation grids in New Zealand.

A selected number of thoroughly assessed photovoltaic demonstration projects are imperative if New Zealand is to become familiar with, adopt, and take full advantage of its own very promising renewable, and abundant energy resource. In particular, experience in the use of distributed grid connected PV systems is warranted now to build up experience for the future.

## ***2.5 Other Solar Conversion Systems***

These solar conversion systems, namely high temperature thermal, solar ponds, ocean thermal and photo-electric chemical, are either at the research stage or are commercially successful only on specific sites not applicable to New Zealand conditions. Although all are promising methods of harnessing solar energy, they are not expected to have a significant impact within the next decade in New Zealand so are covered only briefly.

### ***2.5.1 High Temperature Solar Thermal***

#### ***Technology Review***

Concentration of solar radiation using reflecting surfaces can produce high temperatures. The heat could be used to produce steam to drive either an engine to provide mechanical work (such as water pumping) or to drive an electric generator. Such solar engines were first built in the late 1800s but have been refined substantially since.

Parabolic mirrors are now used to concentrate the solar energy on to one point of focus such as a boiler in front of the mirror. To operate effectively, the mirror must track the sun both in elevation and in azimuth. A variation is the Winston mirror, which concentrates the light to a less precise focus but to the rear of the mirror, which can be a flat area. A further variation is the trough collector, which focuses the light on a line focus (rather than a point focus). This is usually a pipe through which oil or water flows. The trough faces due north and simply pivots up and down to track the sun's elevation.

A well designed point focus parabolic dish collector can achieve a concentration ratio of over 1000 whereas the ratio of a trough collector is only 50 but still adequate for most power plant systems. The higher the ratio, the higher the temperature rise achieved, such that a dish can produce temperatures of over 1500°C and a trough up to 400°C. The same principle of concentration is used in small solar cookers aimed at the developing country market.

The higher the temperature reached the more efficient the conversion system is likely to be. In France in 1969, a 30 m high parabolic mirror was built which faced a large field of heliostats (flat mirrors) facing the sun. The concentration produced a temperature of 3800°C in an area of 50 cm<sup>2</sup>. This technology was used to test components of space rockets and nuclear power stations working at high temperatures rather than to generate power.

Several demonstration/commercial power generation plants based on high temperature solar thermal systems were built in the 1980s. In California, the Barstow 10 MW "power tower" was constructed using a field of tracking heliostats to reflect the sun's rays to a boiler on top of the tower. Molten rock salt, which has high thermal capacity and conductivity, was used to transfer the heat, at 500°C, to drive high temperature steam turbines. The salt can, in theory, store the heat to keep generation going 24 hours a day. However, natural gas is often used as a back-up instead.

The parabolic trough power stations operated by Luz in the Californian Mojave Desert produce most of the world's solar generated electricity. During the 1980s, nine systems ranging between 13 MW and 80 MW were brought on line. The most recent, an 80 MW scheme, has over 46 hectares of collector area. High temperature synthetic oil is the heat transfer medium circulating through the collector pipe. At temperatures of 390°C, high temperature steam is produced via a heat exchanger to drive the turbines. The solar to electricity conversion efficiency is 22% at peak radiation but averages around 14% over the day. This is equivalent to the efficiency of commercial photovoltaic systems.

Current research developments include use of a Stirling engine to more efficiently utilise the high temperatures available from dish collectors. In addition light weight reflective aluminised plastic film is being tested to replace heavy and expensive glass mirrors. The UV light degradation of the film will need to be evaluated.

### ***New Zealand Experience***

No commercial systems are likely to be developed here in the near to medium term due to the relatively low sunshine hours and high capital costs.

### ***Economics***

The latest Luz scheme in California has demonstrated power generation is possible for around \$NZ0.20/kWh, but only when sited in a far higher radiation input area than anywhere in New Zealand. Originally, the Luz solar generation plants competed well with gas-fired power stations, but then the gas price dropped in 1992 and they are no longer viable.

A parabolic trough scheme in New Zealand could generate electricity for perhaps around \$1/kWh and a disk collector would be over \$2.50/kWh, based on overseas cost estimates (IT Power, 1992). Hence, such systems are unlikely to eventuate within the next decade.

### ***Environmental Issues***

Dedicated land would be needed in a prominent sunny position for high temperature solar collectors. Deserts are the obvious location and the power generated could be used to split hydrogen from water, which is then piped to urban centres. It is unlikely any such system will be developed in New Zealand using current technology.

## ***2.5.2 Solar Ponds***

A large salty “lake” area is used as the solar collector. The denser salt water sinks to the bottom and warms up as solar radiation occurs. The less salty upper layer of the pond acts as an insulator so that temperatures at the bottom of the lake rise to around 90°C, which is high enough to run a vapour cycle engine. Solar to electricity conversion efficiencies are low (2%), but nevertheless, from a 20 ha solar pond, 50 MW electrical output has been demonstrated.

The large thermal mass of the pond acts as a heat store so that electricity generation can continue through the night. The main problem is that in the desert, where such systems work most effectively, there is little water and continual replenishment is required. Solar ponds are perhaps more practical to supply drinking water than power generation, using the heat produced for water desalination. Ponds would not be viable in the southerly latitudes of New Zealand. Obviously, the collection surface cannot be tilted towards the sun.

## ***2.5.3 Ocean Thermal Energy Conversion***

In these systems, the sea is used as a solar collector and the small temperature difference between the surface and the cold water at the sea bed is utilised. In deep water, this difference can be up to 20°C. Large volumes of water need to be pumped to make a scheme viable (500 m<sup>3</sup>/s for a 100 MW plant). The small temperature differential in the temperate, shallow waters of New Zealand restricts a viable project from being contemplated.

## ***2.5.4 Photo-electric Chemical Conversion***

Solid-state photovoltaic devices, as described in Section 2.4, absorb light to create electron-hole pairs within their structure. These electron-hole pairs are separated by the p-n junction of the device to drive electric current. Conventional solid-state photovoltaic cells are constructed of semi-conductor materials such as silicon, which has to be of high purity to minimise electron-hole recombination, thereby limiting the efficiency. Alternative approaches to the construction of photovoltaic cells are also being explored. Photovoltaic devices may also be constructed from dye-coated semiconductor materials such as titanium dioxide.

Swiss researchers from Lausanne claim to have developed a cheap yet efficient device based on this method.



Two thin glass plates were covered with a tin oxide layer, which is transparent to light and is an electrical conductor. A thin layer of the semi-conductor titanium dioxide was added to one plate and treated to give it a rough surface to enhance its light absorbing properties. A one molecule thick layer of sensitiser dye was applied and between this layer and the other glass plate placed on top, a thicker layer of iodine-based electrolyte was added.

In such devices, on exposure to light the solar radiation induces the dye molecule into an excited state by absorbing the photons. An electron from the excited-state molecule is injected into the semi-conductor conduction band of the titanium dioxide, leaving the “positive hole” in the oxidised molecule. The electron passes through the semi-conductor to the tin oxide and then into an external circuit ready to do work. It re-enters through the top layer of the conductive tin oxide. The now oxidised dye is reduced to its original state by electron transfer from a recyclable reducing agent, in this case the iodine electrolyte. Thus current continues to flow across the dye-coated titanium dioxide and solution interface as long as light photons are captured by the dye molecules.

Photovoltaic cells of this design are called liquid-junction cells. Their efficiency in converting sunlight to electrical energy is critically dependent both on the light absorbing properties of the dye and how well it is bound to the titanium dioxide surface.

There are a variety of possible dyes that could be utilised in the construction of liquid-junction cells. Metal polypyridyl complexes and porphyrins are two being investigated in New Zealand. Ruthenium polypyridyl complexes are known to be very efficient at light harvesting, but the cost of ruthenium makes electrodes based on this metal too expensive for large scale use. Research is underway at Otago University to produce a generation of copper polypyridyl complexes that will be suitable as replacements for ruthenium. In addition, a joint research project between Massey University and Otago University is investigating ruthenium based systems that would utilise ruthenium more efficiently, thereby making ruthenium dyes cost competitive.

Researchers at Massey University are also hoping to duplicate the way chlorophyll collects sunlight by constructing large arrays of artificial porphyrins. Porphyrins are highly coloured organic molecules that are employed by nature to accomplish a wide variety of tasks from transporting oxygen in blood to collecting sunlight in chlorophyll. Synthetic porphyrins are excellent candidates for dyes, as their light absorbing properties can be widely altered with appropriate substitution or metallation. In addition, a variety of groups can be appended to the porphyrin macrocycle to effect the binding to the semi-conductor. Another variation on this theme involves the use of photoactive conducting polymers, which may represent an alternative to the dyes described above.

The long term goal is to synthesise a “porphyrin polystyrene”, which would be a cheap electro-active polymer lighter than current PV panel materials for the same power output. “Artificial photosynthesis” could then be realised.

The research programme is generic at this stage and will not be commercially viable in the short to medium term.



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## ***Annex 2.1: Developments and Applications of Photovoltaics***

### ***World-wide***

Examples of PV applications in countries most active in research and development are summarised below. Most of this effort involves government supported trials and demonstrations.

- Australia — University of New South Wales and Australian National University, many state and commonwealth research programmes, particularly in remote area systems; state supported renewable RAPS installations; 20 kW tracking flat panel array grid connected interactive PV/power conditioning system at Kalbarri, WA.
- Austria — 800 kWp of stand alone and network connected small scale systems including a 200 kW rooftop programme of 3 kWp units; 40 kWp grid connected motorway sound barrier system funded by the utility OKA.
- Canada — limited demonstration projects to date; preset activities are R&D on system simulation and performance studies; 30 kWp on top of the CANMET building near Montreal; 75 kW rooftop system on the McMillan Rehabilitation Centre supported by Ontario Hydro and EDRL.
- Finland — 20,000 summer houses (mostly off grid) powered by small PV; many small network connected and stand alone demonstration house projects.
- Germany — state backed 1000 roofs programme, 1-5 kW residential rooftop systems with up to 70% cost shared by the government, 4 MW already installed (1994); Bavarian Environment Ministry building, 53.4 kWp of a-Si and mono-crystalline PV panels as sun control “eyebrows”; 2030 m<sup>2</sup> Science Park Gelsenkirchen roof of 300 kWp.
- India — state sponsored programmes (100,000 rural households with solar powered lighting).
- Italy — government supported programme for 25 MW of installed PV capacity by 1996, a number of building integrated demonstrations are under way.
- Japan — MITI programme for 62,000 homes to be equipped with 3 kW grid connected systems within 7 years, \$38,000 50% subsidy per installation; PV roof tiles; semi-transparent wall/window panels; Rokko Island test site, 0.5 MW installation; government expenditure in 1993 was \$3 million on PV component development, \$0.64million on standards and \$17 million on PV demonstrations.
- Spain — 4 MW of small systems in operation, a 1 MW power plant under construction at Toledo.
- Sweden — 20,000 summer houses (mostly off grid) powered by small PV increasing at 5000 per year; many small network connected and stand alone demonstration house projects.
- Switzerland — plan to field 50 MWp of PV by the year 2000, generous government incentives; privately funded scheme with 333 network connected homes of 3 kWp capacity already installed; new commercial building in Berne 115 kWp of shading and cladding panels with reflector augmentation.
- Netherlands — government funded pilot programme for 1000 roof integrated network systems within 4 years, 10 unit housing development in Heerhugowaard with 25 kWp roof integrated networked system with 3 kW inverters; PV systems on hundreds of canal based houseboats, thousands of PV powered water navigation aids; Energy Company of Amsterdam funding for 250 kWp PV installations on 70 buildings; 80 kWp integrated into motorway sound barriers; 600 kWp of rooftop PV for a large scale housing project in Amersfoort.
- Norway — 50,000 vacation houses (mostly off grid) powered by small PV increasing at 8,000 per year; R&D projects into medium scale hybrid PV systems for small communities.
- USA — Georgia Tech. Athletic Centre, 349 kW grid connected (world’s largest roof-top installation -1995); Georgetown University, 338 kW grid connected; PVUSA (PVs for Utility Scale Applications) project, supported by and many US utilities; SMUD Utility has installed over 3 MW of large systems and several hundred residential rooftop systems, rented to customers.
- UK — minimal government support and limited progress towards demonstration systems; the first is University of Northumbria, 40 kW PV wall grid connected cladding in building refurbishment.



### 3 *Bioenergy*

The process of photosynthesis is the means used by plants to convert solar energy into stored chemical energy. The energy is stored in the chemical bonds in the carbon, hydrogen and oxygen containing molecules of cellulose, hemicellulose and lignin which make up plant materials. When used as a source of energy, this biomass undergoes a conversion process to provide heat, power, light or transport fuels. Biomass can take many forms and a wide range of conversion routes are technically possible.

Bioenergy presently contributes approximately 4% (28 PJ) to New Zealand's primary energy supply. This section covers the range of biofuels concentrating on those systems with the greatest potential to contribute further to New Zealand's energy supply within the next decade.

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Note: The proceedings of the conference "Applications of Bioenergy Technologies" held on 12-14 March 1996 at Rotorua provide a more detailed background to this topic and are available from EECA.





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## 3.1 Introduction

It is claimed that at present rates, by 2020 over 80% of the total oil resource will have been depleted, and the last 20% will be very expensive to access (Laherrere, 1995).

As awareness of this situation emerges, there will be increasing pressure on the whole of the energy supply systems, and on the world chemical and materials industries that are dependent on fossil hydrocarbons. Combined with other factors affecting other energy resources and the energy industry, over the next two decades, most regions of the world are likely to encounter increasing difficulties in maintaining historical rates of growth in fossil fuel or nuclear based power generation capacity, and related manufacturing. Along with environmental concerns, this situation is one of the key reasons for the current renewed interest in biomass by a number of governments and large trans-national corporations.

While a wide range of renewable resource/technology mixes (such as wind turbine generators, sun/photovoltaics) can increasingly contribute competitively to power supply, there is a perceived specific need to develop biomass also as a large-scale alternative resource for transport energy and chemical feedstocks. There is increasing talk of engineering a shift from the “hydrocarbon economy” based on finite oil resources, to the “carbohydrate economy” based on renewable biomass resources.

Biomass includes a wide range of products, but all derived originally from recent plant material as a result of the photosynthesis process which provides a store of solar-derived chemical energy. Bioenergy is the heat, light, power and transport fuels which can be provided following conversion of the biomass.

Traditional forms of biomass have provided the basic energy needs for mankind for centuries and still meet 13% of total world energy demand, mainly in developing countries. This report deals with “modern bioenergy”, whereby use of the carbon-based fuels parallels use of fossil fuel. It considers, from the New Zealand perspective, the biomass resource. This includes woody biomass from forests, purpose-grown energy plantations and crops, and municipal solid wastes. The report then evaluates some of the alternative conversion routes which produce the various forms of bioenergy (see Figure 3.1).

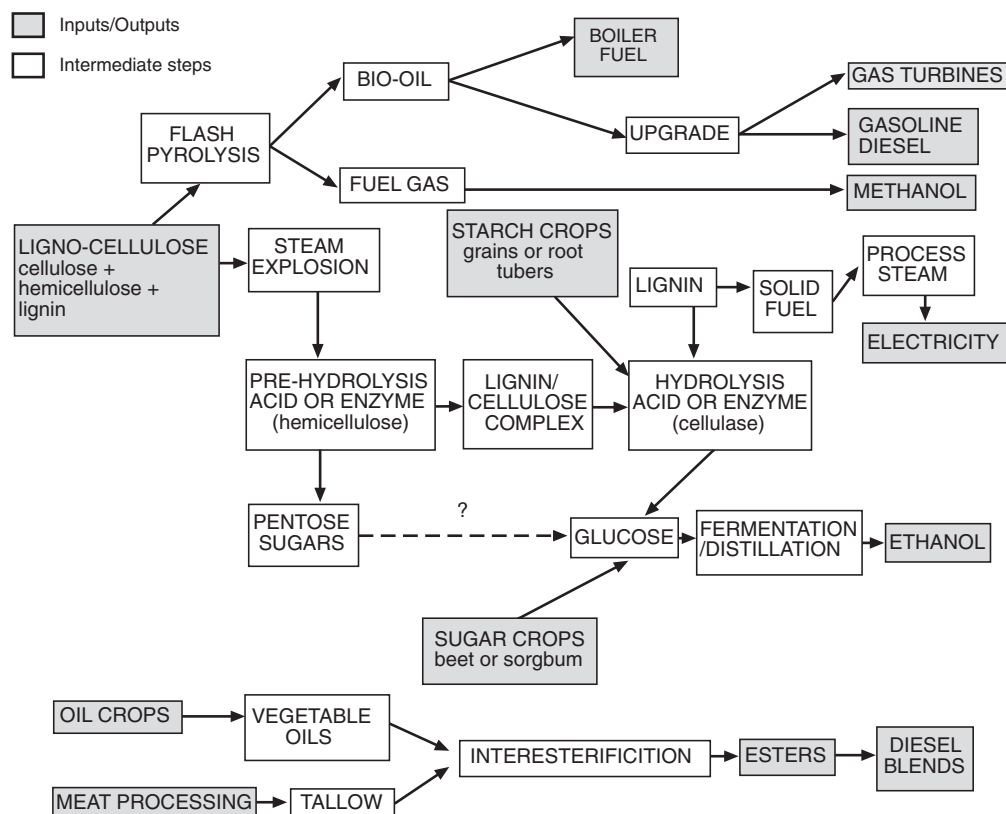


Figure 3.1: The biomass to bioenergy network of conversion routes

### **3.1.1 Bioenergy definitions**

Biomass terminology used in the report is defined as follows.

**Biomass:** Any recent organic matter, originally derived from plants as a result of the photosynthetic conversion process, which is destined to be utilised as a store of chemical energy.

**Bioenergy:** Heat, electric power, light or transport fuels generated as a result of the conversion of a biomass resource.

**Forest arisings:** The unmerchantable above-ground biomass usually left behind in the forest either after thinning, pruning or during the extraction of harvested stemwood, and suitable for use as an energy source.

**Wood process residues:** The bark, sawdust, shavings, offcuts etc., which remain after processing wood logs and timber into useful products.

**Firewood:** Wood, usually in the form of billets (or short, split logs), suitable for combustion in a domestic open fire or enclosed stove.

**Fuelwood:** Comminuted wood that is usually in a chip form or similar so it is flowable and can be used as a feedstock in a range of commercial furnaces.



## 3.2 Woody Biomass

Woody biomass resources as an energy source include arisings (waste materials) derived from conventional forest operations, wood process residues and purpose-grown fuelwood plantations. There are numerous routes available for the conversion of these feedstocks into such useful forms of energy as heat, electric power, gaseous fuels and liquid fuels. This section focuses on the production of the biomass resource as feedstock for direct combustion to generate heat and electricity. Section 3.5 will provide more detailed discussion of the various conversion technologies including gasification and cogeneration.

There are many factors that need to be considered when assessing options for woody biomass supply and its application as a bioenergy feedstock. No single element or process component can be considered in isolation as an overall system approach is required in order that the most reliable and cost-effective supply system can be defined for any given situation.

The following review describes some of the key elements requiring definition by the end users and seek to illustrate potential application of woody biomass for New Zealand.

### 3.2.1 Technology Review

#### **Technology Status**

Bioenergy systems include biomass supply (resource, harvest or recovery and transport), biomass handling (comminution, storage and drying) and energy conversion processes. Utilisation of woody biomass is a commercial reality, technologies ranging from small domestic stoves to large-scale, fluidised-bed, and chemical recovery boilers (Sipila, 1994).

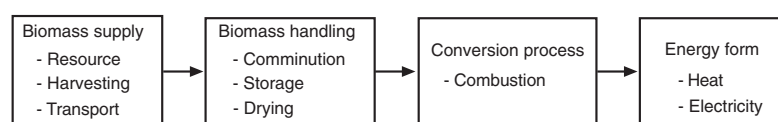
The International Energy Agency (IEA) is at the forefront of world efforts to advance the development and deployment of sustainable energy technologies. It has established a collaborative Implementing Agreement on Bioenergy covering several task areas that now include Biomass Production, Harvesting and Supply, and Biomass Utilisation (IEA, 1994). New Zealand participates in these programmes through the active involvement of the New Zealand Forest Research Institute Ltd (NZ FRI) and other contributors.

The IEA work has indicated that the potential to supply future energy needs from woody biomass is considerable. The introduction of integrated harvesting systems for the recovery of both stemwood and forest arisings and the development of mechanised systems to harvest fuelwood from energy plantations have become increasingly widespread. Five of the participating IEA countries now have operational biofuel systems in place utilising woody biomass (SNB, 1995). The trend is towards increased mechanisation of harvesting as well as central processing of the biomass.

The characteristics of the forest biomass are important in determining the types of processing equipment to provide a fuel to suit the design of conversion system envisaged. Factors such as moisture content, piece size, and type of biomass fuel must be taken into account in the boiler design and selection for a specific site. Research on biomass combustion has been carried out to improve the conversion technologies and to optimise process operations. Studies include those focused on combustion fundamentals, formation and reduction of emissions, modelling of the process, utilisation of contaminated wood waste, oxidation of wet biomass, catalytic combustion, condensing systems, and improvements in co-combustion with coal and cogeneration techniques (Hustad et al., 1995).

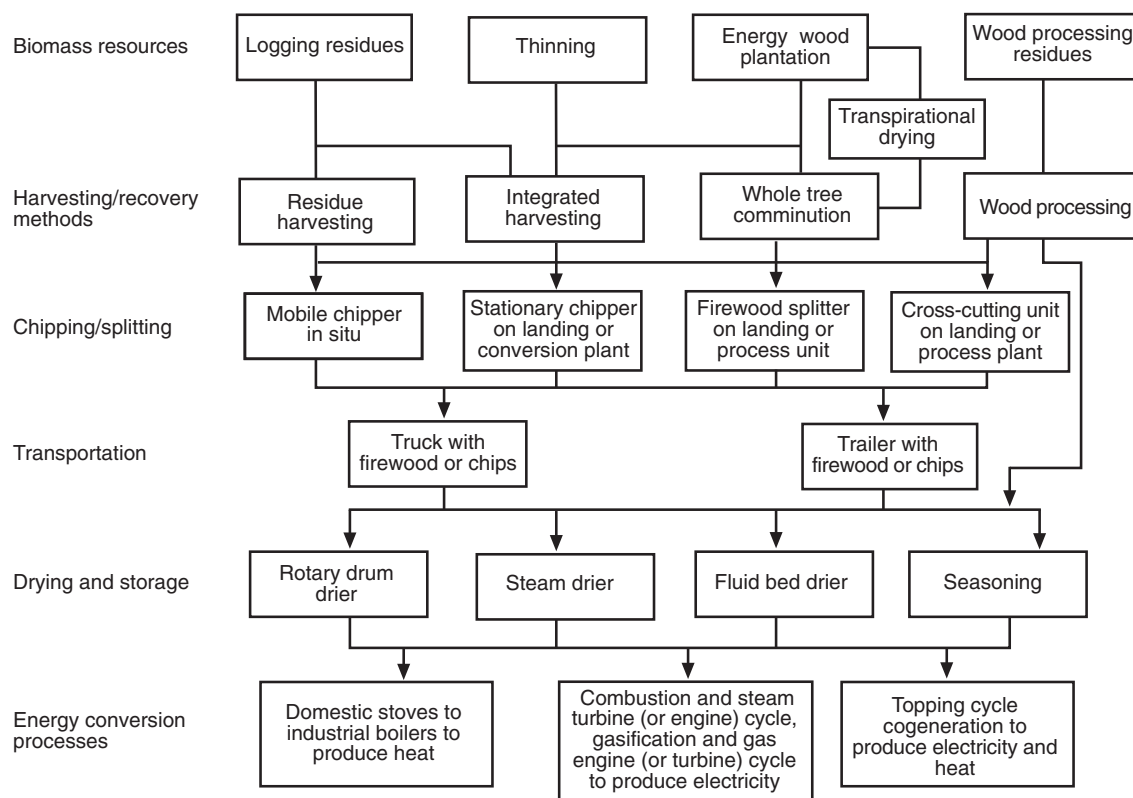
#### **System elements and application**

The elements associated with the production and utilisation of woody biomass are shown in Figure 3.2.



**Figure 3.2: Elements of biomass supply and utilisation for energy production**

The first three elements of this total system can be further refined into separate operations as shown in Figure 3.3 compiled from the point of view of their application to New Zealand.



**Figure 3.3: Components for the production of heat and electricity from woody biomass**

### Supply

Potential woody biomass resources in New Zealand are:

- forest arisings from both production thinning and clearfelling operations in the harvesting of conventional log products such as logging residues;
- fuelwood produced as an additional forest product using integrated harvesting regimes and incorporating in situ recovery (see section 3.2.3);
- purpose-grown energy plantations including short rotation crops and firewood recovery; and
- residues from the processing of timber products.

Woody biomass availability (excluding energy plantations) will ultimately be limited by the scale and nature of New Zealand's primary forest industry. The amount of biomass harvested or recovered will be dependent on a number of other factors including:

- the nature and age class/species distribution of the forested areas;
- the structure of existing forest operations, log markets etc;
- existing transport systems and network constraints; and
- competition between the wood fibre utilisation industry and energy end uses.

For instance, the availability of forest arisings is determined by the harvesting operation employed and the quantities of wood process residues already captured by the fibre products industry. Therefore only a

proportion of the potential energy resource will actually be available for conversion. This resource volume will be further constrained by ecological (environmental), technical and economic factors. The result of these interacting factors means that in the majority of cases, the size of an energy conversion facility will be limited by the amount of resource which can be collected and delivered from within a limited radius of the facility at a cost which allows the overall scheme to be economically viable.

Energy plantations could be grown near the conversion facility to supplement forest arisings and wood process residues. The amount of biomass able to be supplied from energy plantations is limited by the area of available land in competition with land use by other agricultural production systems and also infrastructure requirements. Farmers will grow energy crops only if they can generate a greater income than from traditional pasture products.

### ***Handling***

The comminution, storage and drying of biomass is an important element in the overall energy production chain as this impacts greatly on both combustion efficiency and downstream processing configuration. It is also an important element in rationalising transportation costs which depend on bulk density, and on whether or not artificial forced drying is preferred to transpirational or natural air drying (Overend, 1994).

Processing of woody biomass to chips uses standard equipment designed to produce pulp chips. This results in more cost effective transport and handling systems because of the compatibility with existing systems (Mattsson and Mitchell, 1995). Transport of chips may however create other constraints in the overall biomass delivery system, particularly if long term storage is envisaged. Where this is the case, chipping or splitting of biomass can be done either at the forest landing or at the conversion plant according to the particular economic situation.

In reviewing available techniques for storage and drying of forest biomass, consideration must be given to the effects on dry matter loss, fuel quality and working environment. Results of storage trials in Sweden (Jirjis, 1995) showed that storage of uncomminuted logging residues, in covered windrows or in bundles, and from both fresh and summer-dried material, had many advantages compared with chip storage. The risks of self-ignition and allergic reactions were eliminated and dry matter losses were minimised.

Artificial drying of biomass can be done before storage or before the conversion process. The main types of commercially available driers include rotary driers, steam driers and fluid bed driers (Curvers et al., 1994). Seasoning (which is essentially air drying) is a traditional, uncontrollable, slow drying process which may still be used in some cases, depending on the site and forestry practice. Note that the cost of artificial drying of fuelwood is hard to justify unless waste heat from an adjacent conversion plant can be utilised cheaply.

Transpirational drying of whole trees from energy plantations is feasible. Trees can be left for five to six weeks after felling when transpirational drying can result in a drop in moisture content from around 60% (wet basis) at harvest to 30% (Lowe et al., 1994). However a subsequent handling operation of the whole tree will then be necessary.

### ***Conversion process***

Conversion processes vary depending upon the energy form, heat, electricity and cogeneration of heat and electricity. These are covered in detail in Section 3.5. The primary use of woody biomass in the New Zealand forest sector is for heat production.

### ***Limits of applications and synergies***

The application of woody biomass energy systems is characterised by the site specific nature of the various technical and economic factors involved. The most significant constraints relate to harvesting costs, competition for fibre and competing land use.

The collection of forest arisings as a separate operation after conventional logging is expensive. Integrated harvesting has been suggested as a more efficient harvesting option (whereby whole trees are cut then brought to the landing for processing). Several contractors in NZ are already employing such techniques (Sims, 1994). Detailed operational research studies are being conducted to evaluate the benefits, but results from these

studies are as yet inconclusive (Hall, 1995). Economically recoverable volumes, under a range of harvesting methods and forest types, still need assessing in detail.

One issue that will become more important in the future, is the potential use of woody biomass as a fibre source for paper and board manufacture. Wood process residues are already an important component of the current fibre mix so competition for the resource is a factor which will limit the use of residues as an energy source. Despite such difficulties, however, work undertaken to assess the viability of community-based bioenergy systems (Li et al., 1995) has shown that a strong synergy exists where there are available waste wood biomass feedstocks currently being otherwise disposed.

Glass and Mercer (1995) established models to assess the potential competition between energy and fibre requirements from forest biomass. They conducted a case study based on the Central North Island region which showed that the amounts of biomass available for energy purposes may drop by up to 50% due to competition from the fibre industry. Another model under development by Ford-Robertson et al. (1995) aims to optimise the allocation of woody biomass to fibre processing and energy markets. It is intended that this model be further developed to include information on different types of energy conversion plants and fibre processing mills.

Competing land use is a major barrier to purpose-grown energy plantations. Although there has been a recent downturn in some agricultural commodity prices and the intensity of production per hectare has consequently reduced for some industry sectors, the opportunity cost of land producing traditional food and fibre products, remains relatively high in relation to the current low value of fuelwood (Sims, 1993). However with an estimated reduction of “occupied farmland” from 21 million hectares in 1985 to 17 million hectares in 1993 (Department of Statistics, 1986-87 and 1995) and farmers looking to diversify their products, energy farming could prove to be feasible in the future.

### **3.2.2 New Zealand Experience**

#### ***Present commercial activities***

Woody biomass is a significant (albeit not large) energy source in New Zealand. The accuracy of current biomass energy data is questionable. However, estimates suggest that this resource (which includes pulp and paper waste streams) meets 4% to 5% of NZ's energy needs. This amounts to around 28 PJ/y energy out of the 1994 total primary energy supply of 640 PJ/y (Dang, 1995).

Major users for woody biomass in New Zealand are households and forest industry. Data on use by the domestic sector are particularly limited. A number of energy-use analyses either ignore firewood or group its use with coal. However, firewood is estimated to supply some 4 to 7 PJ/y out of a total energy consumption by the domestic sector of around 42 PJ/y. Estimates of energy supply from wood and black liquor range up to 22 PJ/y (Horgan, 1995). The bulk of this energy wood is used within the wood processing industry, either directly to provide process heat, or through conversion to electricity or both using cogeneration systems. Total energy consumption for the industry is at present some 53 PJ/y (Ministry of Commerce, 1994). The largest single user is the chemical pulping industry where regeneration of the pulping chemical involves burning of lignin contained in black liquors. The New Zealand forest processing industry is thus presently about 40% energy self sufficient. These data exclude energy consumed within the forest.

Bioenergy use in the industry includes heat raising, steam production and electricity generation. A survey of heat and steam production in the New Zealand wood products industries indicated that individual plants have installed energy capacities in the order of 2 to 22 MW output (Dare, 1996).

#### ***Likely commercial developments by 2020***

The forest industry will continue to be the major consumer of energy sources from woody biomass. The commercial development of bioenergy is thus likely to reflect future energy demands from this sector, although other opportunities will exist. Projections of the energy consumption by the future forest processing industry are listed in Table 3.1. These show purchased electricity and in-house energy production from wood and pulp residues are the main energy sources, with in-house energy production expected to rise from 19 PJ in 1990 to about 32 PJ by 2020 (Ministry of Commerce, 1994).

March years	Purchased Electricity	Coal	Fuel Oil	Gas	Geo - thermal	Wood Residues	Pulp Residues	Total
1990	9.5	2.1	1.8	6.8	5.4	6.5	12.8	44.9
1995	11.6	2.4	2.1	7.9	6.3	8.1	15.9	53.3
2000	15.3	2.7	2.4	8.5	6.8	9.9	16.2	61.8
2005	19.0	2.8	2.5	8.9	7.2	10.8	17.1	68.3
2010	21.3	3.0	2.6	9.0	7.5	11.4	17.8	72.6
2015	23.6	3.1	2.7	9.2	7.8	12.0	18.4	76.8
2020	26.0	3.2	2.8	9.4	8.0	12.6	19.1	81.1

**Table 3.1: Projected future energy consumption (PJ) for the forest processing industry in New Zealand (source: Ministry of Commerce, 1994)**

### 3.2.3 Current New Zealand Energy Resource and Potential

#### *Specifications of woody biomass resource*

##### *Forest arisings*

Forest arisings are defined as all unmerchantable above ground biomass left in the forest after harvest of conventional log products. They include branches, tops, unmerchantable stemwood and foliage (Sims et al., 1991). Thinnings from conventional forest operations are also considered as forest residues in this section for the purpose of estimating the potential resource availability.

The proportion of biomass that can be actually recovered depends to a large extent on the harvesting systems used of which there are three broad types (Puttock, 1989).

- Residue harvesting: permits the introduction of wood fuel recovery into conventional clearfell harvesting systems after extraction of the stemwood. In terrain residue systems, the residues are comminuted at the stump. In landing residue operations, the residues are extracted to the landing or to a central processing plant for comminution.
- Whole-tree comminution: produces wood for fuel as the sole product of the harvesting operation. These systems are applicable to early thinning and can use multiple tree handling techniques to reduce handling costs. They are also applicable to harvesting of short rotation energy plantations such as three to four year-old coppice eucalyptus.
- Integrated harvesting systems: combine stemwood and fuelwood harvesting into a single operation. The whole tree is extracted, conventional roundwood products recovered and the tops and branches comminuted for wood fuel. This system could also be applicable to short rotation energy plantation if the stemwood has a pulp value (Sims and Handford, 1992).

##### *Wood process residues*

Wood process residues consist of bark, sawdust, shavings, slabs, cores, dockings, offcuts etc from primary wood processors (such as sawmills, pulpmills, fibre/particle board mills and plywood mills), and secondary wood processors (such as joiners, builders and small manufacturing operations). About 90% of total residues are generated from primary processors, the remaining are produced by secondary processors (Sims, 1993).

Total residue production has been variously estimated at between 35% of the total roundwood volume (Sims, 1993) and 40-45%, derived from an analysis of the Northland and East Coast wood processing industry (Ford-Robertson et al., 1995). The difference between these estimates is due to the different estimation methods used.

Currently around 50% of all wood process residues are used for energy production on site (van Wyk, 1990). For the remainder, part of the available chips from shavings, slabs, cores, dockings and offcuts is used as fibre feed to board and pulp production, some of the bark is used as horticulture mulch, and the rest disposed to waste.

It has been calculated that a further 11% of the materials currently disposed are not contaminated and could be utilised as fuel (Sims, 1993). Residues from secondary processors may be contaminated with adhesives, paints, preservatives and fire protection agents (Marutzky, 1994). In such cases special attention is required in selection of the conversion technology to gain acceptable emissions. In future, residues may increasingly be used as raw material input to board or other product manufacture and this will affect residue availability as an energy source.

### ***Short rotation forest energy plantations***

Woody biomass crops may be grown specifically for energy purposes. A promising means of energy biomass supply is short rotation forestry either utilising a coppice regime or high density plantations. These regimes are often advocated in association with the land disposal of sewage and industrial effluent (Sims, 1993) where yields exceeding 20 oven dry tonnes per hectare per year can be easily achieved given proper management. Field trials of various species, planting densities, time of harvest and rotation length have established that *Eucalyptus*, *Salix* and *Acacia* are suitable species for energy plantations in New Zealand because of their fast early growth, coppicing ability and high wood density (Miller, 1993).

The considerable advantage of coppice management is that subsequent rotations do not involve site preparation or replanting operations (Nicholas, 1993). By resprouting from the cut stumps, coppice shoots have a ready access to water and nutrients available in the soil through an already existing root system. The rotation length under such a management regime is generally of the order of three to five years when planted at a population of 4000 to 5000 trees per hectare. The whole tree above ground can be utilised.

On the other hand, lower density plantations on longer rotations can produce a greater proportion of stemwood biomass, are more compatible with conventional harvesting techniques, but generally require replanting after harvesting. Rotation length is typically from seven to 12 years for populations around 1000 to 2000 trees per hectare.

### ***Firewood***

Traditional supplies of domestic firewood come from land clearing, forest arisings, small sawmill residues, wind thrown trees and general scavenging (Sims, 1993). Some firewood plantations based on short-rotation plantations have been grown by private owners to supply high quality firewood to meet projected increased demands for domestic, wood-burning appliances. Estimates of current firewood demand are difficult to obtain but the 1986 census indicated wood was used as a heating fuel in approximately 50% of dwellings. The Department of Statistics (1992) showed there to be 352,000 enclosed stoves and 322,000 open fires installed, consuming 300,000 tonnes of wood and 100,000 tonnes of coal annually (Centre for Advanced Engineering, 1996). An average annual consumption of 1.7 m<sup>3</sup> of solid firewood (4.3 GJ) was estimated for each household burning wood for heating (Sims, 1993).

### ***Quantity - technical potential and useable potential***

The technical potential is a measure of the theoretical woody biomass supply available whereas the useable potential allows for environmental, technological, social and commercial constraints to its production and use. Information and assumptions pertaining to the woody biomass resource estimates are summarised below together with the estimates thus derived.

### ***Forest arisings***

Plantation forests are attractive as an energy resource because of their scale (1.4 million ha) and the technical capability of the New Zealand forest industry to deliver a practical energy supply to the energy consumer. Many interacting factors such as the age class distribution of the forest, the silvicultural regime, market demand and economic conditions will impact on future supply.



The distribution of plantation forest sites in New Zealand is given in Table 3.2. Conditions differ for each of these locations so confidence can only be given to technical estimates of the energy resource which reflect forest inventory and operational planning data for known plantation operations.

Site	Forest Area (ha)
Northland	134,000
Auckland	77,000
Central North Island	529,000
East Coast	89,000
Hawkes Bay	81,000
Southern North Island	91,000
Nelson/Marlborough	138,000
West Coast	28,000
Canterbury	80,000
Otago/Southland	140,000
Total	1,400,000

**Table 3.2: Plantation forest sites in New Zealand (source: NZFOA, 1995)**

The availability of forest arisings from plantation forests in New Zealand has been previously estimated by Sims (1993), and Hall and Wylie(1996). Glass and Mercer (1995) also provided detailed estimates of the forest arisings estimated to be available only from the central North Island region (Table 3.3).

Reference	Sims (1993)	Hall & Wylie (1994)	Glass & Mercer (1995)*
Proportion of residues based on weight of wood harvested	19%	Stem waste: 2.5% from ground-based, 4.7% from hauler Branch waste: 1.8% from ground-based, 7.9% from hauler Ratio of ground based to hauler logging — 70:30	Estimated 46%
Component of residues	Recoverable unmerchantable stemwood and tops	Recoverable unmerchantable stemwood and branch	All unmerchantable material including stemwood, branch, needle and thinning
Quantity of residues	Useable	Useable	Technical
1991-1995 (ODt/y)	510	441	2,589
1996-2000 (ODt/y)	650	496	2,976
2001-2005 (ODt/y)	940	735	4,192
2006-2010 (ODt/y)	1,110	NA	4,416

Notes: ODt/y = oven dry tonnes per year

\*Extrapolated from Central North Island data

**Table 3.3: Comparison of different forest arisings estimates for New Zealand**

For the purpose of this report the results of Glass and Mercer (1995) were extrapolated based on forecasts of future log wood supply in New Zealand (Turland et al. 1993) to provide a further estimate of the amount of forest arisings technically available. It should be noted that estimates depend on the nature and age distribution of the forest and the harvesting system assumed. Glass and Mercer (1995) considered all unmerchantable



material would be recovered leading to a recovery of about 46% by weight of the total log harvested. In practical terms, however, it is extremely unlikely for this to be the case, and hence the estimate given should be regarded as representing an upper limit to the technical potential supply from the Central North Island.

In practice, estimates of useable quantities of forest arisings that might potentially be available need to take into account two additional factors;

- **Recovery efficiency:** the proportion of the forest arisings that can be actually recovered. This will depend on the harvesting system deployed. Sims et al. (1991) reported a brief trial result using a whole-tree harvesting system and suggested that as much as 54% of the total unmerchantable biomass could be recovered from a 30 year-old *Pinus radiata* stand.
- **Competition for fibre feedstock:** the recovered biomass diverted to direct use as fibre will reduce the available quantities. A figure of 50% was assumed in a study undertaken by Li (1994) of the potential availability of forest arisings for energy production.

The useable potential quantity of forest arisings available as a woody biomass resource estimated according to these two factors was approximately 0.7 million ODT/y in 1991-1995, increasing to almost 1.2 million ODT/y by the year 2010 (Table 3.4).

	1991-1995		1996-2000		2001-2005		2006-2010	
Potential	Technical	Useable	Technical	Useable	Technical	Useable	Technical	Useable
Forest arisings								
ODt/year x10 <sup>3</sup>	2589	699	2976	804	4192	1132	4416	1192
PJ/year	49.2	13.3	56.5	15.3	79.6	21.5	83.9	22.7
Processing residues								
ODt/year x10 <sup>3</sup>	1419	710	1474	737	1647	824	1679	840
PJ/year	27.0	13.5	28.0	14.0	31.3	15.6	31.9	16.0
Energy plantations								
Plantings (ha)		500		5000		5000		5000
ODt/year x10 <sup>3</sup>		5		75		75		75
PJ/year		0.1		1.4		1.4		1.4
Firewood								
ODt/year x10 <sup>3</sup>		380		404		480		960
PJ/year		7.2		7.7		9.1		18.2
Total available								
PJ/year		34.1		38.4		47.6		58.3

*Energy values for forest biomass were assumed constant for the different resource categories. Typical net calorific value of 19.0 MJ/kg of oven dried material was assumed considering the different residue types and species (Baines, 1993)*

**Table 3.4: Estimates for the annual technical and useable quantities of woody biomass resources in New Zealand**

### Wood process residues

The total volume of wood process residues from roundwood varies with the processing methods used for the different wood products. It will also vary with technological improvement. It is thus very difficult to arrive at an accurate figure based on the average proportion of residues likely to result from roundwood processing.

A comparison of the assumptions by Sims (1993) and the data derived by Ford-Robertson et al. (1995), suggests that residues make up around 40% by volume of total roundwood processed which is a realistic estimate for the purpose of this study. This gives an estimated biomass resource, based on Ministry of Forestry roundwood consumption estimates (Ministry of Forestry, 1993), of about 1.1 million ODT/y. As a conservative estimate it was assumed that this will be the amount of residues produced from roundwood by the year 2010.

In addition potential quantities of available bark have been estimated at 368,000 ODt/y in 1991-1995, increasing to 628,000 ODt/y by 2010 based on total wood harvested (Maplesden, 1994). The total potential quantities of residues including bark is thus estimated at 1.4 million ODt/y in 1991-1995 increasing to 1.7 million ODt/y by 2010 (Table 3.4).

In considering the competitive use of residue chips for pulp and board manufacture and the use of bark for horticultural mulch and chemical extraction, there is insufficient information to suggest what the future situation might be. For this study, however, 50% of the technical potential quantity was assumed to be diverted to these uses, thereby reducing the residue volume available for energy production. This is an area requiring further investigation.

Available quantities of wood process residues including bark as a woody biomass resource were therefore 710,000 ODt/y in 1991-1995, increasing to 840,000 ODt/y by 2010 (Table 3.4).

### *Energy plantations*

Sims (1996) reported an estimated mean annual yield of 20 ODt/ha/year of harvestable biomass for coppice eucalyptus on a three year rotation based on the results from a number of field studies. With improved agronomic knowledge and plant selection, higher yields should be feasible. Small plot trials at Massey University have shown, for example, the mean annual increments of *E. brookerana* to average over 24 ODt/ha/year (after four harvests on a three year rotation with no irrigation fertiliser or weed control), and 72.6 ODt/ha/year for *E. globulus* at five years old planted at 3200 trees/ha. No breeding or selection programmes have been undertaken to date.

Where such blocks are grown in association with the land disposal treatment of sewage and industrial effluent, high commercial yields may be possible. A biomass yield of 30 ODt/ha/year can probably therefore be assumed for future energy plantations. These yield estimates are supported by the work of Frederick et al. (1986) who demonstrated dry biomass yields of 36 ODt/ha/year over a two-year period for a 5-year-old *E. nitens* plantation grown in the Central North Island. Previous analyses have taken the more conservative yield of 20 ODt/ha/year as appropriate, based on current agronomic knowledge (Sims, 1993).

Land availability for energy plantations is difficult to determine as it is dependent on future gross margins of competing agricultural products. Farmers will only produce energy crops if they can achieve a higher return per hectare than from growing traditional products (Sims, 1996). Although in New Zealand there are now 3-4 million hectares less land under production than 10 years ago, this land is mainly high country and is therefore unsuitable for energy plantations. Sims (1993) projected available land area for energy plantations to be around 500 ha in 1992. This could theoretically be increased to 656,000 ha by the year 2012 based on the potential availability of suitable land areas and a planting of 30,000 ha/year on average. However, infrastructural requirements and competition from other land uses would have a significant impact on these projections.

In Sweden, 12,000 ha of short rotation willow have been planted since 1990 for energy purposes (Bahn, 1995). Appropriate pricing and infrastructures were established to encourage this new industry. Given political will, similar growth could occur in New Zealand. There is also the likelihood in New Zealand of competition for feedstocks from fibre and pulp industries. The stemwood harvested from energy plantations potentially useable for pulpwood was measured at around 50% to 60% of the total tree weight (Sims, 1993). Accordingly the potential biomass production from energy plantations is difficult to estimate. For the purpose of this study, therefore, only a nominal 5,000 ha land establishment was assumed for future planting. This gave an estimate of 75,000 ODt/y fuelwood available as woody biomass resources in 1996-2000, remaining constant out to the year of 2010, which was considerably lower than the estimate used in the Ministry of Commerce *Renewable Energy Opportunities* report (Sims, 1993).

### *Firewood*

The best available estimate for firewood supply was that provided by Sims (1993) and substantiated by the Centre for Advanced Engineering (1996). The forecast figures in Table 3.4 reflect an increase in installation of domestic, wood-burning appliances. A survey of current firewood demand is presently being undertaken in Auckland. The results, available in March 1996, may allow for improved estimates.

*Likely changes in supply by 2010*

Table 3.4 shows the forecast of potential energy supply from woody biomass to 2010. The energy supply able to be realistically deployed will be limited by the balance of energy demand and the feedstock availability. The cost of biomass supply will also be a key factor in determining uptake of the technologies.

Forest arising availabilities are related to stemwood production. New Zealand currently has an annual harvest of about 17 million m<sup>3</sup> wood, including roundwood and logs (NZFOA, 1995). The forests are dominated by younger age classes so it is anticipated that the annual wood production will double by 2010. Therefore available forest arisings are also likely to double.

Wood process residues are related to the roundwood processed and bark production. The amount of roundwood processed within New Zealand will be dependent on future world markets for timber and the extent to which further investment in manufacturing occurs. An assessment from 1971 to 1992 showed that roundwood consumption has remained reasonably consistent over time. Currently approximately a third of the harvest is processed locally (Ministry of Forestry, 1993). This indicates a constant tendency for local roundwood consumption and suggests that the quantities of wood process residues will thus remain essentially constant out to the year 2010. Bark quantity increases as wood harvest volumes increase. Considering both these aspects, total wood process residues have a tendency for slight growth up to the year 2010.

Energy plantations were not seen as a significant contributor to the woody biomass resource. This source could potentially supply much greater amounts of bioenergy but this will depend on future government strategy (or intervention) to develop more opportunity for conversion of available land to establish energy plantations as has occurred in Sweden.

Firewood demand is projected to increase slightly due to population growth and the anticipated reduction of natural gas resources.

### **3.2.4 Environmental and social aspects**

In the context of global CO<sub>2</sub> levels and climate change, bioenergy has considerable environmental benefits. It does not contribute to increases in the atmospheric concentration of carbon dioxide where the resource is sustainably managed (Ericson, 1993). Environmental systems are discussed in detail by Bridgwater et al. (1995) with regard to the nature and control of solid, liquid and gaseous emissions from thermochemical processing of biomass.

Recovery of forest arisings and whole-tree harvesting will generally reduce the requirement for site preparation to clear logging debris to facilitate re-planting. Broadcast burning, to either facilitate planting or to reduce the fire hazard would also be avoided (Dyck and Maclaren, 1993).

There are several potential negative impacts from using woody biomass including emissions, soil nutrient status, biodiversity, wildlife habitat and water quality. Biomass combustion can emit small quantities of particulate, nitrogen oxides and will also generate ash, the nature of which has yet to be fully assessed.

The increased biomass removal of whole-tree harvesting results in a disproportionate amount of nutrients being removed from the site because of the greater concentration of nutrients in the foliage and branches compared to the stemwood (Dyck and Maclaren, 1993) and the increased amounts of this material being recovered. Nutrients removed at harvest can be replaced, through natural inputs (eg., biological nitrogen fixation), by fertiliser additions or by ash return, but all require active management. At present, residues left on the forest floor also provide habitat for a diverse range of organisms. There are some pressures on forest managers to protect these values.

In addition, removing protective slash cover from erodible soil surfaces may increase sediment loading to streams and lakes thereby becoming a pollution source, particularly to surface water. On the other hand, conventional logging systems can result in accumulation of debris at the landing which has Resource Management Act implications. Removal of these materials may be a future requirement placed on forest managers and thus their collection for use as an energy source will have avoided cost implications.

### 3.2.5 Economics

This section is limited solely to consideration of the cost of delivered biomass to a conversion facility. Energy conversion economics are not included. The cost factors thus include energy crop production, collection/harvesting, feed preparation, and delivery/transport. Cost data are expressed in second quarter 1995 NZ\$ values derived by inflating the various published data in accordance with the Producers Price Index of Outputs by Forestry and Logging (Statistics New Zealand, 1995).

#### **Forest arisings**

A recent case study of the central North Island (CNI) region to assess the economic availability of forest arisings for energy production (Glass and Mercer, 1995) applied a system analysis based on linear programming methods to *Pinus radiata* plantation management. The analysis covered the costs of recovering the arisings, chipping at the landing site, and transporting the chips to a hypothetical conversion facility. Although the characteristics of the CNI forests differ from elsewhere in New Zealand, the findings of the study were assumed to be applicable for all New Zealand. This region contains approximately 40% of New Zealand's exotic plantation forests by area. For more specific resource assessments, individual sites should be subject to separate analysis.

#### **Present supply cost**

This base case was based on current forest harvesting technology. A motor-manual system was assumed to be used for production thinnings and clearfelling operations on both tractor and cable logging terrain. On tractor terrain, machinery capable of travelling through production-thinned and over cutover sites provided the operational basis for arisings recovery in situ. No such cutover scavenging operations were undertaken on cable logging terrain where, for safety reasons, current motor-manual harvest practices involve delimbing at the landing rather than in situ where the felled tree lies. Delimbing at the landing, coupled with the tendency for cable logging systems to drag debris onto the landing, concentrates forest arisings at these sites and allowance was made for machinery engaged in arising recovery at landings. A portable chipper was assumed to process the extracted arisings at the landing in both tractor and cable logging terrain, with the chips being ejected from the chipper onto a waiting chip freighter. Chip transportation cost was calculated assuming an average transport distance of 80 km from the stand to a conversion plant.

The average cost arrived at for this base case was \$147/ODt (\$7.7/GJ), with arisings derived from production thinning being more expensive, \$166/ODt (\$8.7/GJ), than arisings from clearfelling operations, \$140/ODt (\$7.4/GJ), primarily because of differences in piece size of the recovered material.

Hall (1995) recently conducted a field study on collection and transport costs of logging residues. The study evaluated three systems for collection of stem waste wood from logging landings and their transport to a chipper site (or conversion plant).

- System 1: Sorting and stacking of waste wood from skid surrounds by excavator.
- System 2: Waste wood extracted from skid surrounds and heaped for removal by an off-highway 6-wheel drive self-loading dump truck.
- System 3: Extracting waste wood from heaps created on skid sites with a 6-wheel-drive highway truck with self-loading crane and grapple, conventional logging bolsters on the truck, and a 3-axle bin trailer.

The delivered residue costs for the three different collection systems were \$35.00/m<sup>3</sup>, \$70.00/m<sup>3</sup> and \$24.00/m<sup>3</sup> excluding the purchase price of the wood. Assuming a residue basic density of 0.415 ODt/m<sup>3</sup> similar to that of wood (Kininmonth and Whitehouse, 1991) and a net calorific value of 19.0 GJ/ODt (Baines, 1993), the costs ranged from \$3.0/GJ to \$8.9/GJ. These figures will be higher than the results of Glass and Mercer (1995) since chipping costs are included.

#### **Future supply cost**

For comparison purposes, cost estimation for a scenario incorporating future harvest technology trends was also conducted by Glass and Mercer (1995). This scenario modelled an integrated harvesting system based on tree-length extraction and mechanised delimbing at the landing where forest arisings are concentrated.

Arisings recovery costs on tractor terrain were taken to be zero, but on cable logging terrain were assumed to be similar to those for the motor-manual system. Compared with this base case scenario, lower chipping costs were assumed on account of forest arisings being larger in terms of piece size. Transportation costs remained the same.

While the mass of recovered residues and the average clearfelling age were similar to those obtained in the base-case scenario, they may have been overstated because no cutover scavenging was specified. Future scenario production costs were significantly lower than the base case, ranging from \$57/ODt (\$3.0/GJ) to \$89/ODt (\$4.7/GJ).

### ***Cost sensitivity analysis of the key factors***

The recovery system, piece size and transport distance are the three key factors to influence forest arising supply costs.

Using a motor-manual recovery system as in the base case, arising recovery costs proved to be the highest cost component because of the expense of cutover scavenging operations. By comparison the future scenario, using an integrated harvesting system to eliminate cutover scavenging, reduced the average cost of delivered biomass significantly.

The piece size presented for chipping will relate to the productivity and energy consumption of the chipper. Piece size does not relate only to chipping, but also depends on the recovery system used.

Transportation is an important part of the supply chain contributing 20-40% to the delivered fuel cost (Mattsson and Mitchell, 1995). The high cost relates particularly to the low bulk density of chipped woody biomass. In order to get a full payload within maximum allowable load dimensions, the load requires a bulk density of 250-280 kg/m<sup>3</sup>. However, typical bulk densities for fuelwood chips are in the range of 120-150 kg/m<sup>3</sup>. Therefore, it has been suggested that compaction trailers be used for economic transport. Alternatively arising chips could be utilised close to the available source. In the longer term, this could entail the development of a portable wood-fired power plant located in the forest.

## ***Wood process residues***

### ***Present supply cost***

Most of the wood process residues used for energy are combusted on site. For many of these residues the delivered cost can be considered to be zero or negative. Some residues are currently disposed of by burning or dumping off site. Costs typically range from \$1.3/GJ to \$6.4/GJ (Sims, 1993). If such residues can be on-sold to other industries, the disposal costs are avoided. The subsequent user may pay little more than nominal costs.

There are competing demands for residues from fibre feedstocks (chips, sawdust) and garden mulch (bark). Ford-Robertson et al. (1995) estimated an opportunity cost of around \$3.2-\$6.4/GJ for these materials. Thus, wood process residues can be assessed at a fuel cost of between \$0.0/GJ and \$6.4/GJ for use both on site and off site depending on the particular site situation.

### ***Future supply cost***

There are a number of factors that influence future supply costs. Technology development to utilise bark for extraction of chemicals, and the competitive use of chips for fibre feedstock, will potentially reduce the quantity of residues for energy production. This will result in either an increase in the residues cost as a feedstock for energy production, or increased opportunity to use other biomass resources. The opportunity costs for fibre and chemical extraction are thus likely to become the benchmark for future pricing.

## ***Energy plantations***

A previous study of energy plantations (NZFRI, 1993) showed the profitability of conventional fuelwood production to be low unless substantial prices can be realised for the fuelwood source. Sims (1993) undertook a life cycle cost analysis for large scale energy plantations using short rotation coppice fuelwood production for a 90 ha block. Biomass production costs consisted of site preparation and fencing, tree seedlings and



planting, fertiliser application, weed pest and disease control, land opportunity cost, harvesting costs for 3 year old trees and transport. Assuming a coppice plantation would only have a twelve year life before it needed to be re-established, indicative delivered fuelwood costs were suggested to be in the order of \$2.50/GJ to \$5.00/GJ (in second quarter 1995 NZ\$ values).

### *Firewood*

The retail firewood price varies with source, wood species, region, time of year and quantity purchased. Production of domestic firewood is more labour intensive for sawing, splitting, bagging etc than chipping and may involve additional marketing and delivery costs. A common upper figure for delivered firewood from firewood lots, scrub felling or old shelter belt is of the order of \$25.5/GJ (Sims, 1993). Where personal/family labour can be employed, and the wood is free, a common minimum cost of \$2.6/GJ is possible allowing for chainsaw, trailer and car fuel use.

In future, firewood costs could reduce in real terms if firewood production is commercially related to fuelwood plantations on a large scale.

### *Resource cost curve data*

The present and future useable biomass resources from Table 3.4 and their present supply costs are combined in Table 3.5. The medium, and low degrees of confidence given to the estimates indicate the quality of estimation and reflect the accuracy of information on the quantity and costs of the resource.

Forest arising estimates were given a medium confidence level because current plantation forest estates are well known and the areas available for harvesting in 2010 can be reasonably predicted. However, collection methods are still in the development stage. For wood process residues, the current quantity of processed roundwood is known, but the proportion of residues from the wood processed was assumed and the components for different uses are unclear. Since only a small total area of energy plantations has been established to date, future plantings and yields are impossible to predict with any accuracy, so its estimate has a low confidence. Firewood estimates have a low confidence level due to there being insufficient information on sources.

Resource	Supply 1991-1995 (PJ/y)	Supply 2006-2010 (PJ/y)	Fuel cost (\$/GJ)	Confidence
Forest arisings	13.3	22.7	3.0-8.7	Medium
Wood residues	13.5	16.0	0-6.4	Medium
Energy plantations	0.1	1.4	2.5-5.0	Low
Firewood	7.2	18.2	2.6-25.5	Low
Total	34.1	58.3		

**Table 3.5: Woody biomass resource supply and delivered fuel costs**

## **3.2.6 Constraints and Opportunities**

Constraints and opportunities for development of wood-fired energy generation have been recently summarised by Sims (1994). These are abstracted as follows;

### *Production barriers*

The collection of forest arisings is an expensive operation. Integrated harvesting of wood could be a more efficient option. Several contractors are already employing such techniques but detailed operational research

studies are required to evaluate the benefits. The recoverable volumes under a range of harvesting methods and the potential replication need assessing in detail. The Logging Industry Research Organisation has recently began such assessments (Hall, 1995).

Residues from wood processing operations can be used on site as a fuel but a significant proportion is still disposed to waste. In the future though, even that utilised now as fuel may have competing uses for fibre feedstock as technology improves and/or the pulp price increases.

### ***Handling barriers***

Reducing the moisture content of woody biomass feedstocks assists efficient conversion. Transpiration drying of whole trees from short rotation energy plantations to around 25% to 30% moisture (wet basis) has been trialed in New Zealand. New drying processes to reduce the moisture content to 10% to 15% are being developed for woody biomass (Convertech, 1995).

### ***Conversion barriers***

The optimum size of wood-fired energy generation plant is linked to the economic supply of the feedstock and hence the volume of the available local resource. The relatively high capital costs of wood combustion plants compared with coal or gas relate to the low energy density and the variability of the fuelwood resource.

Large central conversion plants could lower the unit prices but the fuel requirements of such plants would be high, and hence average transport distances to the plant would be greatly increased (Ford-Robertson et al., 1995).

The image of biomass as a fuel is poor in New Zealand due to the old and inefficient designs of many wood-fired plants still in use. It is not well understood that state-of-the-art conversion technology is now more reliable, more efficient, virtually non-polluting and can be automatically controlled. Gas turbines to replace steam turbines will be a significant improvement once these applications are fully developed. Capital constraints are also a contributing factor to the slow uptake of these technologies.

Development of small scale conversion systems for localised use may reduce feedstock treatment costs. However the small-scale equipment tends to be more capital intensive in terms of \$/kW output, and is still requiring commercial demonstration. Fluidyne, a New Zealand gasifier manufacturer of 50 kW plants has recently announced plans to design and construct a 500 kW Mega Class gasifier/gas engine generator set to be demonstrated in Germany (Williams, 1996).

### ***Opportunities***

New Zealand has low a population density, a temperate climate and fertile soils which are ideal for biomass production. It already has a significant bioenergy component meeting its primary energy requirements. Estimates of potential energy supply by forest biomass (Table 3.4) show that forest arisings, wood process residues, energy plantations and firewood could potentially contribute as much as 34.1 PJ/y in 1991-1995, rising to 58.3 PJ/y by 2010. With development of production and handling systems, there is potential to deliver woody biomass fuels which are cost competitive with other forms of energy.

## ***3.2.7 Further research requirements***

There is a need to determine appropriate methodologies for comparison of biomass resource estimates including the evaluation of biomass production systems.

The recovery of forest arisings is not only related to the recovery efficiency for economic energy production, but is also related to the environmental aspects such as nutrients removal, wildlife habitat and site protection. Therefore, research is needed to optimise forest arisings recovery efficiency to balance economic and environmental impacts. Detailed operational research is required to evaluate the benefits of integrated harvesting systems.

Identification of accurate quantities and energy end-use data of wood process residues is needed to establish



feedstock requirements for the different conversion techniques. A particular need is the requirement for improved information on the markets for bark and other wood process residues.

Energy wood and domestic firewood supply from purpose-grown energy plantations is being trialed at various sites within New Zealand. Improved technologies in planting, harvesting and handling need to be developed. Short-rotation energy plantation research directed towards optimising biomass production systems in terms of GJ/ha/year and preferred feedstock species is required. The link between land treatment of effluent and the nutrient stripping ability of fast growing, short rotation tree plantations needs to be further explored.

Determination of the effects of biomass feedstock properties on the performance of industrial biomass combustion systems need evaluation. The drying, storage and handling of biomass are all important components in the optimisation of boiler performance. In addition, work is required to characterise the environmental impacts of utilising woody biomass as an industrial fuel.

Economic comparisons of the conceptual portable wood-fired energy generation plant versus a large central conversion plant need to be conducted for the NZ situation. Development directions and economies of scale could thus be better assessed and established.

The development of system analysis capability is needed to examine the economic effects of competition, environmental externalities and end-use options on the overall viability of biomass production systems.

Further research should act in unison with the IEA Bioenergy Agreement to obtain rapid transfer of new technology and its deployment in New Zealand industry.



## 3.3 *Agricultural Biomass Crops*

Biomass in the form of energy crops is already used on a large scale in a number of countries. The Brazilian gasohol scheme, which produces ethanol from sugar cane, is well known; the USA has over 8000 MWe of installed biomass fuelled power generation capacity, a significant proportion of which includes farm residues; while world-wide over 1 billion tonnes of sugar cane are processed annually in sugar mills fuelled with bagasse, the residue from the process. Beyond these pioneering uses, bioenergy is being developed as a new industrial sector in a growing number of industrialised and industrialising countries.

### 3.3.1 *Technology Status*

Biomass has long been recognised as a potentially large source of renewable energy, organic chemicals and composite building materials. Its large scale use, however, has been impeded by several key problems:

- the high moisture content of most freshly-harvested biomass;
- the presence of alkali salts in some types of biomass makes it difficult to combust in high efficiency, high temperature boilers or gas turbines;
- difficulty in accessing, refining and converting the valuable chemicals biomass contains, which have the potential to substitute for petrochemicals in a wide variety of uses; and
- the relatively low energy density.

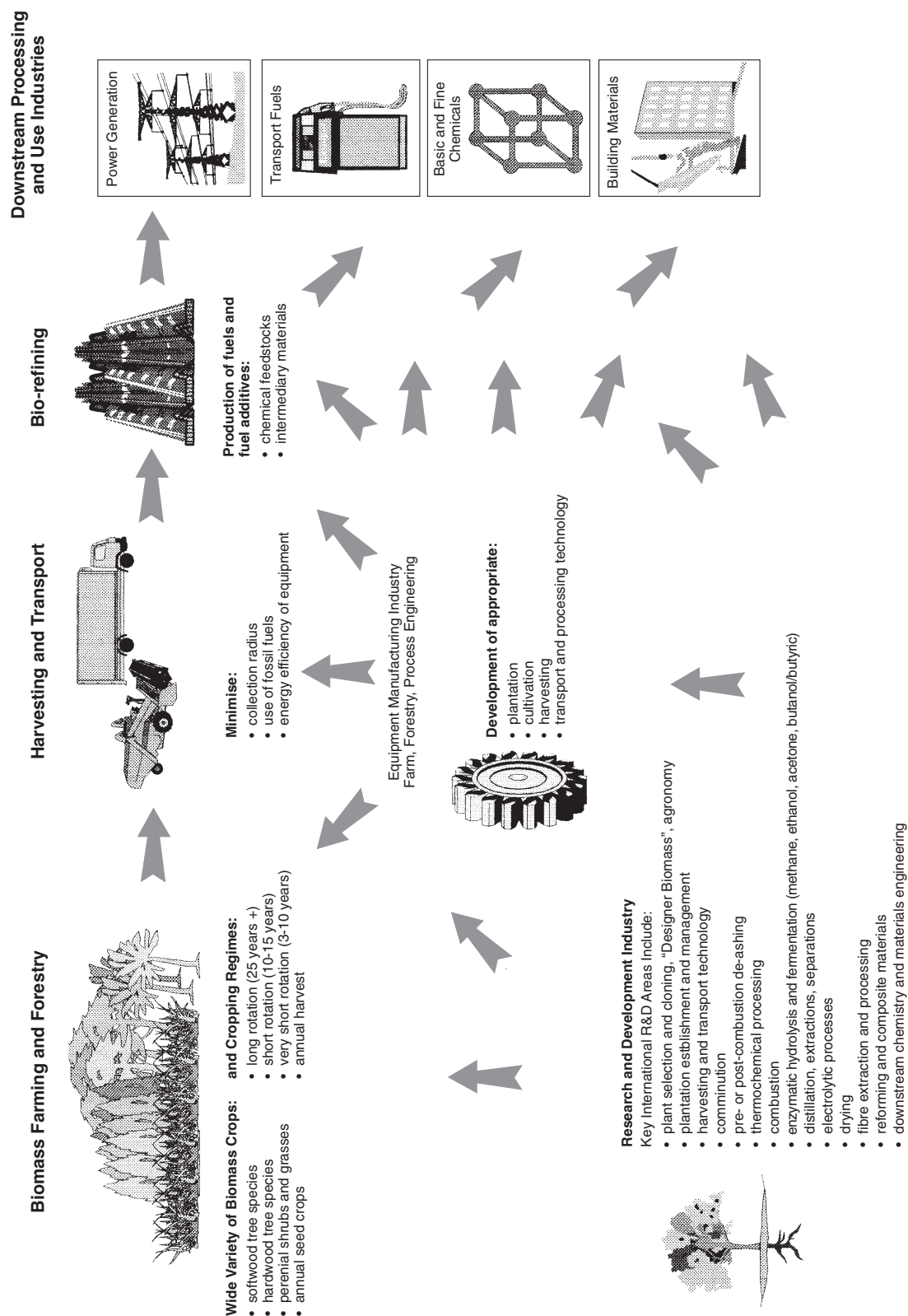
The development of agricultural energy crops should involve an understanding of the overall emerging bioenergy industrial chain as this development conditions strongly what takes place at the farm level.

Energy is only one component of biomass crops. Whether it be in the form of straw, short rotation coppicing, corn, broom, *Miscanthus*, etc., biomass is a chemically complex material. Just as it would not make economic or environmental sense to process milk only for skim milk powder and to reject the fat and all other constituents, it would not always be sensible to produce most biomass forms to process them into a single energy product. Fractionation and refining of non-food, non-feed biomass crops into a range of chemicals, materials and energy co-products should be evaluated.

At the farm or plantation level, crops offer good prospects when they can interweave seamlessly with existing food or feed production. This means that while some food or feed production might be displaced, the new biomass crops must be integrated within farming systems that are sustainable in economic, social and environmental senses.

The main components of the emerging bioenergy industry are outlined in Figure 3.4. Key technological developments include the following.

- Plant selection and cloning genetic mapping. Biotechnologies and robotics are used to develop and mass produce clones with desired characteristics to meet market and processing requirements.
- Agronomy. Growing non-food and fibre crops is a different business than traditional farming. Recent developments indicate the feasibility of achieving very high but sustainable annual yields (expressed in dry matter per hectare) based on low energy and low materials inputs.
- Harvesting and transport. The trends are towards supplying biomass in flowable small particulate forms and to minimise energy input costs.
- Comminution. In many cases in biomass production, additional comminution is necessary, as in the sugar beet and cereal straw industries.
- De-ashing. Ash levels are a major issue impeding the efficient use of the energy embodied in some forms of biomass. Hot gas cleaning and scrubbing after the gasification stage, or de-ashing prior to thermochemical processing, are being investigated, as is returning the ash to the land to recycle the elements.



□Figure 3.4: The emerging biomass industry

- Drying. Some biomass contains 50% water, whereas straw can have a moisture content as low as 10% (wet basis). Low moisture content feedstock is preferred for combustion and gasification which are covered in section 3.5.
- Processing. Whatever the downstream use, biomass must undergo some form of refining and conversion. Combustion and gasification are the most common. There is an almost bewildering range of processes currently under development. Most work revolves around various forms of “lysis”, that is the breaking down of biomass into its main chemical constituents using a range of chemical and physical processes, including hydrolysis, solvolysis and pyrolysis.

### ***Implications at the Farm Level: Towards “Designer Biomass”***

The implications of the development of the biomass refining industrial chain outlined above are extremely important at the farm level. Contemporary food crops, world-wide, are the results of a long process of development often extending into the millennia. This evolution occurred in close interaction with downstream uses and was governed by their needs. In more recent years, under the effects of some scientific arrogance and barriers between disciplines, the need for this close interaction was sometimes forgotten. In Europe, for example, in the 1970s, new high yield wheat strains were developed and marketed, only for the flour milling and baking industry to point out that the resulting flour was not “panifiable”, that is, had extremely poor bread making characteristics and thus close to nil market value.

Similarly with biomass, the challenge is to achieve the selection, improvement and development of crops in a relatively short span of time (that is, in practice, within a 30 to 60 year period) to meet downstream industry requirements. In other words, the challenge is for the development of “designer biomass” tailored for processing by biomass refining industrial chains.

The main lessons learnt so far as a result of R&D efforts to meet this challenge are listed below.

- Think in terms of farming systems since crops do not exist in isolation. The unit of activity is the farm or plantation. From a sustainable development perspective, individual crops need to be integrated into sustainable systems tailored to specific locations and taking into account physical parameters such as crop rotation requirements, soil quality maintenance, pluviometry, wind, temperature regimes, hydrology, etc., and also economic, social and cultural aspects relative to local farming communities. In other terms, they must be developed with reference to specific *terroirs*. The notion of *terroir* has no direct modern English equivalent. In Maori, a close equivalent is *whenua*. The loose translation of *whenua* as “land” does not fully convey its meaning.
- Achieve sustainable high yields in terms of tonnes of oven dry matter per hectare per year (odt/ha/y). In industrialised countries, 15 odt/ha/y would be a bare minimum in most situations, 20 odt/ha/y is a reasonable objective, and some farming systems achieve over 40 odt/ha/y but few would be presently sustainable at this level. This translates directly into the economic viability of crops under specific regional economic circumstances and acceptable farmers’ incomes.
- Produce the molecules and fibre as required by downstream processing industries, which preferably leads to a stream of co-products. For example, there is a large potential market for furfural, which privileges plants with high C<sub>5</sub> sugar content such as cereals and hardwoods. The German car manufacturing industry is fostering the development of flax and other crops that produce economic and easily recycled fibre for use in cars. This work leads to ease of recycling and improves overall energy efficiency over the products’ life cycle. A stream of co-products is essential to quickly achieve competitiveness.
- Produce crops that can be harvested on a regular basis and can be established quickly. Although farm forestry is expanding, farmers have a distinct preference for crops that can produce an early and steady annual return instead of having to wait for over 20 years until forest type trees are mature and ready to harvest. Short rotation energy forests fall between annual crops and traditional forests in this regard.
- Select crops that can be grown and harvested with minimal changes to existing technology and with minimal additions to existing farm capital equipment, at least in the initial development phase. In most industrialised areas, a considerable amount of capital equipment has already been invested at farm levels for food production. Much of this equipment can also be used for certain types of biomass crops with little

or no modification. This would ease considerably the financial burden through a transition to non-food crops, reduce the learning process for growers, and hence considerably speed up the transition process.

- Develop crops that can be delivered in the form of small particles to the first processing plant in the industrial chain. Crops that can be harvested green and delivered in small particulate form considerably minimise overall energy costs. This militates in favour of crops that can be harvested with conventional forage harvester type machinery, although there must be a compromise between annual yields, desirable moisture content and harvesting method.
- Choose crops that can be stored easily unprocessed once harvested (such as in silage form) and, if possible, that can be harvested all year round (such as coppice Eucalyptus) to minimise losses and reduce overall capital costs of storage.
- Choose crops that have a low ash content or that can be easily de-ashed at the first processing stage to considerably minimise downstream processing costs. This militates in favour of straw-like crops and crops that can be easily comminuted, such as brooms.
- Carry out plant and cultivars selection and cloning designed to achieve the above objectives.

A wide array of plant species exists that meet the above criteria, but only a few (such as sugar cane, hemp, rubber wood) are being used on an industrial scale for energy and other non-food uses, and few are being investigated systematically for such uses (such as *Miscanthus* or very short rotation *Salix* species). Other promising species currently being investigated include switch grass, *Arundo*, energy cane, bamboos, various *Polygonums*, corn, sweet sorghum, *Triticale*, brooms, and a wide range of tree species. Most of this work, however, is still at the R&D and demonstration stage. While some industrial biomass crop applications already exist on a large scale (such as sugar cane in tropical areas, combustion of straw in Denmark), the science is still in its infancy. Much R&D is required and there are very strong and profitable prospects for improvement.

Another important implication of the above criteria and trends is the increasing irrelevance of the traditional distinctions between farming and forestry. Such distinctions applied when these land uses catered for very different types of downstream industrial requirement and constraints (such as the need for solid wood, or starch products). Farmers, traditionally, have grown trees (for fruit and nut production), vines (for hops, kiwifruit, and wine), and annual herbaceous crops (such as cereals). At present, a major and increasing fraction of the demand from the traditional clients of the forestry sector is not for solid timber but for fibre and particulate material. The global demand for long cycle solid wood production used for fibre and particulate processing is merely the result of history and may dwindle in the long term in the face of new and more competitive sources.

In other words, there is a nascent convergence between farming and forestry towards the production of:

- low energy crops using low inputs;
- short rotation tree crops;
- environmentally sustainable farming or plantation systems; and
- fibre, energy, chemicals, and materials as co-products.

Large scale development of biomass for non-food, non-fibre, would not necessarily compete with food production. With available technology, it could complement food production in integrated sustainable farming systems where the whole plant would be processed instead of a small part of the plant. In addition, a much greater variety of plants would be used instead of a few monoculture species, as is now too often the case. In economic terms, all of this can be done without the need for on-going government subsidies.

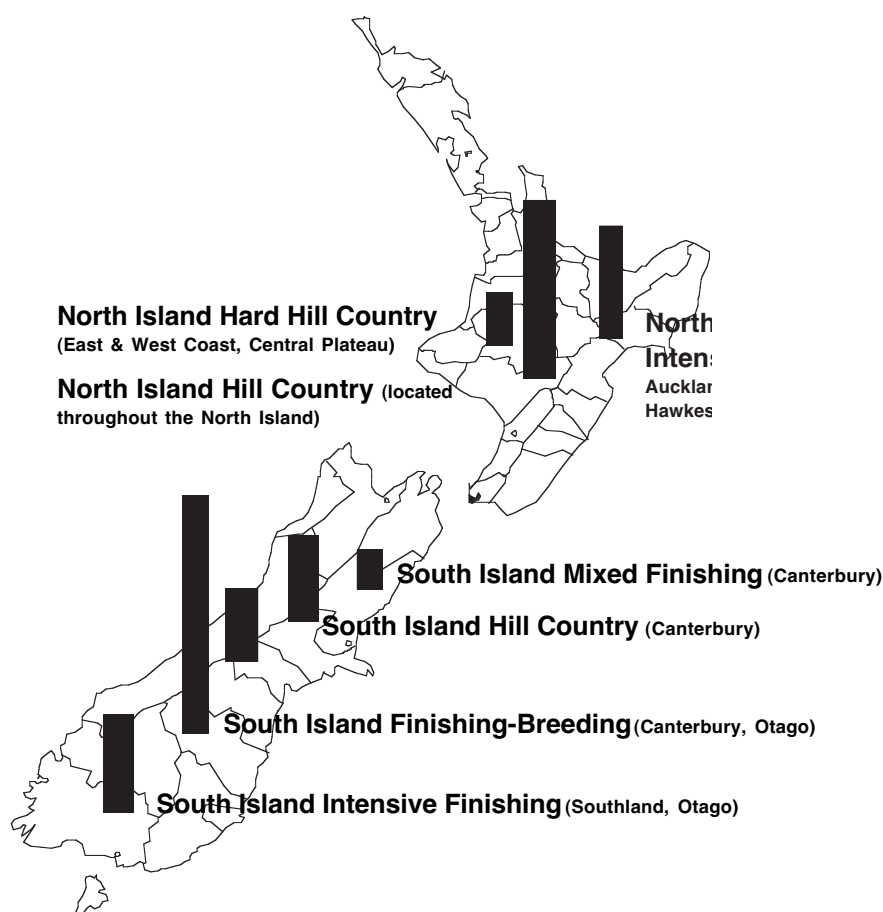
Even contemplating relatively low yields per hectare initially (that is, if using most locally suitable species “as is” without the benefits of much plant and cultivar selection), there is enough land available globally to substitute for current world oil production and beyond, and certainly enough in New Zealand to meet the local energy demand, but at the expense of exported agriculture products. With improved cultivation and selection methods (“designer” biomass), higher sustainable yields would be achievable in the longer term.

### 3.3.2 New Zealand Experience and Potential

The New Zealand potential for biomass crops is currently largely unexploited. As an industrialised country with strong farming and agro-industrial sectors, New Zealand has accumulated substantial expertise in all the scientific fields required for such a development. There is considerable interest among a wide range of crop and food researchers who wish to pursue R&D programmes in this broad general area, and there is a nascent industry developing novel downstream processing technologies. In parallel the country enjoys a low land to population ratio and has large tracts of suitable land under a favourable temperate climate.

The land use potential for biomass was extensively investigated by the New Zealand Energy Research and Development Committee (NZERDC) during the early 1980s. This work had indicated that in addition to existing forestry, a large amount of pastoral land could shift to energy farming under suitable economic conditions (Harris, et al., 1979). More recent analyses, based on state-of-the-art technology and a suite of economic assessment models, indicated that, on a preliminary basis, over 5,000,000 ha could become available without disturbing substantially the current food production. This would represent an energy potential of over 8000 MWe (Arnoux, 1993a).

A summary of the geographical distribution of the potential land resource is presented in Figure 3.5. This only takes into consideration land that is flat or gently rolling, and where biomass can provide a better return than wool and meat in terms of gross profits per hectare. Other types of farming such as dairying, and mixed cropping have not been included as they have a higher gross margin opportunity cost.



**Figure 3.5: Economically competitive New Zealand biomass production potential**

The implications are substantial not only in terms of power generation but also exports of products (chemicals and materials), technology, and available expertise. FRST's *Energy Research Strategy* (1995) recognised that, in the context of new and emerging sources of energy: "New Zealand appears to have particular advantages because of its climate and high economic dependence on growing biomass".



In recent years, New Zealand's farming sector has been under considerable stress, and experienced an overall economic decline as measured in terms of the change in gross economic output. Biomass production has the potential to reverse this trend and revitalise major segments of the farming sector while in parallel expanding the forestry sector into new areas beyond timber, pulp and paper.

### 3.3.3 Potential Supply and Trend to 2010

To be competitive, bioenergy developments must be grounded in sustainable well integrated farming systems that include a number of biomass crops managed under sustainable rotations. The industrial profile and spectrum of potential species are such that the land resource available could be developed to achieve yields averaging 20 odt/ha/y. A substantial measure of seasonal and annual variability is to be expected, owing to the range and nature of New Zealand climates, and terroirs. The harvesting and storage systems must be designed to easily accommodate such variations.

Biomass development potential must be seen in a context where:

- power generation capacity is expected to become constrained after the turn of the century;
- Maui gas reserves are set to dwindle within the first decade of the millennium and earlier than expected;
- a large proportion of New Zealand's coal reserves are expensive to mine;
- considerable uncertainty affects future use of fossil fuel reserves in regard to international negotiations and actions with respect to such issues as the greenhouse effect, and economic instruments such as the much debated "carbon tax";
- New Zealand has abundant and under-utilised land resources which, at present, are not farmed in a sustainable manner, and are providing parts of the farming sector with a severely constrained and often uncertain source of income;
- New Zealand has access to emerging multi-product biomass processing technologies, that is, producing from the same biomass raw material, as co-products, a range of chemicals and materials as well as heat and power.

Overall, this gives biomass crop developments a high level of commercial resilience compared with present pastoral farming. It also enables the competitive implementation of biomass production and processing on a large scale, without the massive subsidies other approaches still require.

In such a context it is difficult to accurately forecast what the potential supply of energy from crops might be in 2010. A very wide range of equally valid scenarios must be contemplated. One possible development path is shown in Figure 3.6, whereby biomass would meet, commercially and competitively, a very large proportion of the country's energy and materials requirements. What quickly becomes clear when contemplating such scenarios, however, is that comparatively little of this potential is likely to eventuate by 2005 if development processes are left to so-called "market forces".

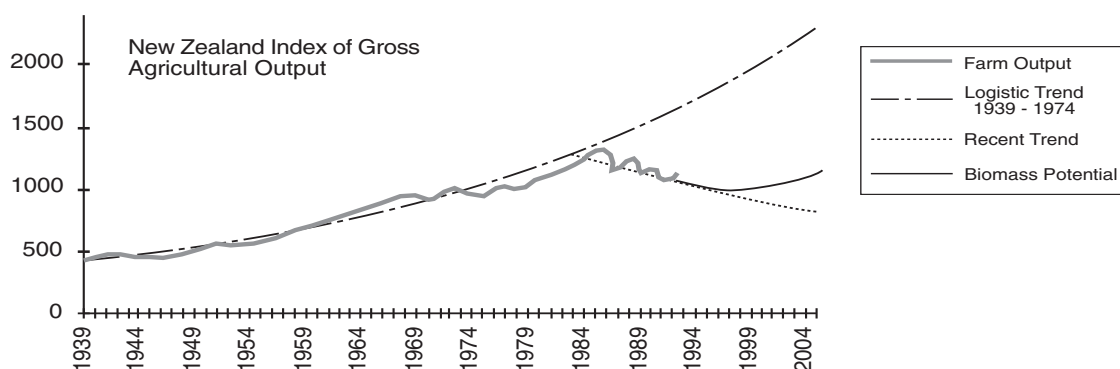


Figure 3.6: Growth, decline, and potential regrowth of the New Zealand farming sector based on biomass

### 3.3.4 Environmental and Social Aspects

The potential impacts of biomass crop developments are multifaceted. Potential effects will have regional, national, and trans-national implications in environmental, social and economic areas.

#### **Environmental**

- (1) Local Environment. The technology development profile analysed earlier is such that biomass is treated as a total resource in which every component has its uses. In such a context, local environmental effects are essentially positive in terms of sustainable management of the land with effects such as erosion control, improved ground cover, improved hydrology, improved soil vitality and humus content, etc. Some processes, such as ethanol production from fodder beet, result in large volumes of effluent that require disposal. On the other hand, by products from the biodiesel production from oilseed rape provide a high protein meal and combustible straw.
- (2) Global Environment. At the global level, the use of biomass as a source of fuel is a possible answer to the greenhouse problems arising from fossil fuel use. The only carbon dioxide emitted is non-fossil based, as it is the CO<sub>2</sub> absorbed by the biomass from the atmosphere during photosynthesis as part of the ongoing carbon cycle. Once released by combustion or material decay, the carbon atoms are recycled again via the biomass plantations.
- (3) Managing the Resource. By opening the way to the creation of biomass crops as a large scale sustainable resource, the present technology development has the potential to significantly alter the management of existing resources (such as deciding or not to dam wild rivers, invest in further gas and oil exploration, and so on). Further, because of the relatively small scale of biomass crop processing plants (in particular, in order to minimise transport costs) and the short crop establishment and rotation time spans, resource management issues can be dealt with in a flexible and incremental manner (as opposed to more traditional large investment projects such as large hydro dams that have to be planned and implemented over a decade or more).
- (4) Visual Impacts. The production of energy crops on a large scale, whether annual or perennial, herbaceous or woody, will change the rural landscape. If grown as large areas of monoculture crops this could be offensive to many people. However, if planned properly as advocated in Sweden (Perttu, 1996) the landscape (and wildlife) could benefit.
- (5) Other Issues. Intensive planting could have an effect on the local water table depending on crop species. If evapotranspiration rates are high, less water will be available for downstream users in the catchment area, but this is unlikely to be problematic in most regions of New Zealand. Indeed, it could prove advantageous where the crop is also grown as a vegetable biofilter to absorb water and nutrients from sewage, farm and industrial effluents and sludges.

Overseas studies of arable coppice crops have shown a greater diversity of flora and fauna produced both within and at the margins of the crop. This is due to less frequent disturbance of the crop and land than occurs with pasture or annual crops. The situation under New Zealand conditions has yet to be determined.

Transport of large volumes of biomass to the conversion plant and storage of the feedstock will be a necessary component of the system which will have an impact on local residents.

Emissions resulting from the bioenergy conversion process vary greatly with crop and product; those from biodiesel production from oilseed rape being less than from combustion of woody biomass to produce electricity for example. In addition, the technology used results in different emission levels. For example, gaseous emissions from a modern wood gasification plant will be much lower than from a less efficient combustion plant. Considerable research on emissions is being undertaken overseas. This will need to be closely reviewed to determine the possible environmental burden of a specific energy cropping system. Overall, the emissions are likely to be more favourable than from the equivalent use of fossil fuels.

#### **Social and Economic**

Potential social and economic effects of biomass crop developments are extremely broad. They encompass immediate and short term concerns but also contribute to significant long term changes. They include:

- the perennial issue of job displacement and creation;
  - economic multiplier effects in the regional and national economy;
  - export potential and foreign exchange earnings;
  - progressive change of ethos in the area of energy supply and use;
  - change towards a stewardship approach to resource management and human settlement.
- (1) **Employment and Economic Multipliers.** Job creation and multiplier effects are closely related. In addition to the immediate creation of new jobs within biomass crop processing chains (biomass farms, biomass harvesting, collection and transportation, initial processing and downstream further refining) employment and other economic effects replicate through upstream suppliers (such as farm machinery), downstream users, and the local economy supplying workers. Such multiplier effects can be gauged effectively through input/output economic models. For example, two inter-industry models were used, one for the Canterbury region, and one for the whole of the New Zealand economy (Arnoux, 1993a). The models indicated that for each extra dollar of output by the utility industry in Canterbury and based on biomass crops, there was a total increase in the output of the local economy of \$2.10. This translated into a 2.6 income multiplier ratio (that is direct, indirect and induced income effects were 2.6 times the initial effect in the utility sector), and a 3.1 employment multiplier. Similarly, at the national level, the input/output data indicated multipliers of 2.5 for output, 3.3 for income, and 4.0 for employment. Each increase in output by \$1 million at the utility industry level (taking into account the induced reduction in pastoral output) would generate 12 extra jobs. This is consistent with overseas estimates (Wood and Whittier, 1992) which showed strong multiplier effects for income and employment from biofuel developments in the US. Overall, the development of biomass industrial chains would have extremely positive effects on the economy and on the employment front.
- (2) **Export Potential:** The export potential of the set of technologies and expertise related to biomass crop development is considerable. Such developments could lead to the creation of a new export sector for related equipment, engineering expertise, and products.
- (3) **Other Social Effects:** The combination of the above effects has the potential to revitalise rural communities in many parts of the country. The large scale development of biomass crops as, in part, a non-fossil fuel source of energy, is likely to lead to a progressive change of ethos in the areas not only of energy supply but also of use. As demonstrated by the US experience, local, and relatively small scale, power generation based on biofuel is extremely amenable to cogeneration. This aspect will facilitate the development of energy efficiency at the user level, and of least cost integrated planning of supply and demand. This represents two significant types of change that will have flow-on effects in terms of energy use attitudes and behaviour. Similarly this approach would lead to a change towards a stewardship approach to resource management and human settlement. A move away from the exploitation of finite stocks of fossil fuels, and towards sustainable production entails a considerable change of perspective. To ensure long term sustainability, biomass based industrial chains entail on-going maintenance and development of the land, soil, hydrology and technology development in the areas of biomass production and use.

### 3.3.5 Economics

Owing to the nascent state of biomass crops, analysing the economics is extremely difficult. Overseas data is not usually relevant to New Zealand conditions and often does not account for the most recent technological advances.

The literature on biomass plantations has tended to consider tree planting for traditional fuelwood uses (either domestic or industrial). Sims (1993), for example, considered planting at 5000 stems per hectare and coppicing at three years, to give overall biomass costs of about \$95/odt. This regime was selected to maximise the energy yield in terms of GJ/ha/y, but such a regime is not designed to meet all specific industry requirements, as outlined earlier.

Similarly Williams and Larson (1993) quoted figures for Eucalyptus energy plantations in Brazil and

estimates for Poplar in the US to be in the order of \$78/odt and \$105 respectively. These examples were based on rotations of 6 years and annual yields of only 13 to 14 odt/ha, which can lead to higher harvesting and transport costs. In some instances, drying costs might be required, adding a further \$20/odt, but this is avoided by transpirational drying of whole trees.

A suite of biomass crop establishment, maintenance and harvesting techno-economic models that simulate commercial farm or plantation operations over a period of up to 20 years (the notional life of a processing plant) were used in the following analysis by the Converttech Group Ltd in developing their biomass refinery (Sections 3.4.1 and 3.5.2). These models were coupled with other models of biomass fractionation and processing plants to assess the overall economics of biomass industrial chains.

The analyses focused on three main type of situations:

- (1) short rotation coppicing trees: such as Eucalyptus with high plantation densities translating into high yields and small diameter stems thus facilitating harvesting, transport and processing;
- (2) annual perennial crops: such as Miscanthus or cane plantations developed on the model of sugar cane plantations, and harvested annually at the optimum dry matter content per hectare;
- (3) perennial new crops: such as broom and Polygonum farms, coppiced and harvested all year round.

The models compute establishment costs, harvesting and storage capital equipment requirements, plantation running costs and harvesting operational costs. The data is then integrated into provisional cashflow and profit and loss accounts for the lifetime of the project. The values of all parameters are derived from commercial values for the various regions under consideration.

Table 3.5 presents estimates of biomass prices designed to achieve a 9% internal rate of return in a worse case scenario where the land and all equipment are purchased at establishment time, with 75% of capital borrowed at 10% interest.

		<b>Eucalyptus</b>	<b>Miscanthus</b>	<b>Broom</b>
Plant Sizes	odt/h	20	20	20
Biomass Price	\$/odt	31	22	11
IRR	%	9.00%	9.00%	9.00%

**Table 3.5: Plantation biomass prices**

These model results constitute a first approximation of what is achievable under New Zealand economic and climatic conditions. The figures are not directly comparable with the estimates from the overseas and New Zealand literature quoted above because they rest on a significantly different approach and set of technologies. The biomass price range/odt translates into energy prices of \$0.60 to \$1.60 per GJ, that is, competitive with natural gas. The \$1.60/GJ top end of the range is for short rotation Eucalyptus, which Sims (1993) calculated to be between \$2.50-4.00/GJ, as outlined in Section 3.2.5.

The IRR of 9% was chosen so as to provide an attractive rate to farmers and to be competitive with current forestry expansion. In this regard, McLaren (1993) indicated that about 5 million hectares of farmland were exploited in unsustainable ways under current pastoral regimes, which if converted to forestry could attract IRRs of 7% to 9%.

Table 3.6 summarises the average profit before tax that would be achieved under the three models, while Table 3.7 presents a summary of pastoral farm levels of profitability and a first approximation estimate of pastoral farmland suitable for plantation development. In Table 3.6, the labels refer to the type of farm or plantation described above rather than the actual species modelled.

These two tables show that, under the assumptions made in the models, the profit/ha to be made from energy plantations would compare favourably with most types of pastoral farming. Under these conditions, about 5 million hectares could be considered for plantation development. This translates into an energy potential of

Potential for Biomass Farming in New Zealand	Land Suitable for Plantation	Average Profit Before Tax		Average Farm Size	Estimated Number of Farms	Estimated Farming Area	Flat Area/Farm	Rolling Area/Farm	Normal Rainfall
	(000 ha)	(\$/ha)	per Farm	(ha)		(000 ha)	(ha)	(ha)	(mm)
North Island Hard Hill Country	305	65.7	39380	599	1650	988	31	154	1535
North Island Hill Country	1053	129.0	49796	386	4700	1814	44	180	1408
North Island Intensive Finishing	647	202.4	44930	222	3350	744	84	109	1200
<b>Total North Island</b>	<b>2005</b>				<b>9700</b>	<b>3546</b>			
South Island High Country	447	1.7	17529	10203	250	2551	1012	777	756
South Island Hill Country	500	12.4	19278	1558	900	1402	320	236	760
South Island Finishing Breeding	1428	49.5	18720	378	4450	1682	178	143	748
South Island Intensive Finishing	620	192.7	36620	190	3300	627	114	74	937
South Island Mixed Finishing	263	129.9	34413	265	1000	265	215	48	668
<b>Total South Island</b>	<b>3260</b>				<b>9900</b>	<b>6527</b>			
Weighted Average (All Classes)		70.5	36216	514			126	143	1078
<b>Total</b>	<b>5264</b>				<b>19600</b>	<b>10073</b>			

(Source for base data: NZ Meat and Wool Board Economic Service Farm Survey Data, 1993)

**Table 3.7: Pastoral farming profitability and land availability**

over 2800 PJ per year (compared with current primary energy use of about 640 PJ). Conversely current primary energy requirements correspond to an area of less than one million hectares.

	Average Profit before Tax	Average Plantation
	\$/ha	ha
Broom	105	9391
Eucalyptus	545	4968
Miscanthus	191	4968

**Table 3.6: Average profit before tax for biomass plantations**

These figures do not constitute accurate estimates of land availability. They simply indicated that ample land would be competitively available for energy farming.

The NZERDC energy farming study, which focused on production of transport fuels (Harris et al., 1979), estimated much higher levels of land availability for a wider range of crops. However, it had similarly concluded that:

“an area of less than one million hectare would provide the majority of transport fuel requirements in 2000.” (p. 24)

Overall the data indicate the economic viability of developing large scale biomass crop supplies in New Zealand based on existing technology. Future improvements could result in increased profitability.

The models have been further refined to simulate random price fluctuations for all key parameters and to assess the probability of achieving over 10% IRR over the life of the project (Monte-Carlo simulation). Under most situations contemplated, the models gave over 95% probability of achieving the set IRR.

### 3.3.6 Constraints and Opportunities

The very substantial opportunities biomass crops offer have been noted earlier under the evaluation of the resource potential. It was also noted that comparatively little of this potential is likely to eventuate by 2005 if development processes are left to so-called “market forces”.

Market processes are known to be extremely efficient to regulate exiting markets in open economies within existing industrial sectors. Achieving the biomass potential implies the development of new farming and industrial sectors, and the creation of new market dynamics. The corresponding socio-economic processes are those that can achieve a transition from one set of “market forces” to another one. History shows that existing “market forces” can be slow in ensuring such transitions, even when economic factors are clearly favourable (Arnoux, 1992a).

This is being recognised in a growing number of countries in Europe and the Americas, where a wide range of initiatives are being undertaken to facilitate the transition. Central to this approach are:

- the notion of partnership between relevant government agencies and private sector interests; and
- the use of well targeted funds (from public and private sector sources) to foster the required R&D, and demonstration, and to facilitate early commercial implementation.

A variety of instruments can be used to mobilise such funds such as low level industrial sector levies, and/or low level levies on energy use. The reticulation of the New Zealand rural sector was painlessly achieved through such a low level levy (Arnoux, 1993b and 1993c).

It can be argued that it is time for a “Biomass Initiative” to:

- provide the catalyst needed to realise the country’s competitive advantage in biomass;
- use this catalyst to set in train a series of commercial developments; and
- promote the administrative, regulatory, and fiscal changes that are required to create market conditions that would facilitate the development of economically viable projects in this area.

While the market is ideally suited to decide what form of energy is appropriate to each particular circumstance, governments have a role to play in shaping the markets to facilitate the necessary transitions. Following an overseas renewable energy fact finding mission in 1995, the Minister of Energy stated: “the role of the government is to make sure that all environmental externalities are internalised in the price of energy and to develop well functioning competitive markets.”

Recognising that the present administrative, regulatory, and market mechanisms were not designed to meet these criteria, new initiatives may be developed in the future.

For example, a sequence of steps to initiate the need to change could be:

- Create a small team of dedicated and experienced people from the private and public sectors with a common interest in this area.
- Ask this team to develop a framework for a robust private sector — government partnership aimed at developing biomass processing as a new industry.
- Define and develop a programme of actions to assess and demonstrate the technologies and their potential.
- Identify and promote R&D initiatives to capitalise on present advantages and maximise benefits (such as through downstream processing of fine chemicals from biomass or plant selection and breeding of “designer biomass” material).
- Identify and promote specific public and private sector initiatives to create and improve the market conditions for the development of the new farming sector and industry.
- Organise the means to monitor and publicise progress.



The Energy Efficiency and Conservation Authority (EECA) has already initiated a dialogue between relevant parties, which led to the creation in January 1996 of the Bio-energy Network New Zealand (BNNZ).

### **3.3.7 Research Requirements**

Research requirements must develop the domestic potential for bioenergy or be considered from a strategic global perspective. In terms of the R&D work New Zealand teams are best placed to undertake in a competitive manner. The earlier review of key global technological developments can assist to pin-point such areas.

- Land use and sustainable resource management. There is an urgent need to develop suitable assessment tools to define optimum use of the land, and select sustainable development paths. Such tools would be ideally designed to be transparent and facilitate negotiations between stakeholders in potential development schemes. In parallel, there is a need to develop a more detailed assessment of the biomass potential in the various regions of the country.
- Plant selection and cloning. Major progress is taking place overseas in this area, including the use of robotics for plant multiplication. Some of this technology is being introduced into New Zealand, but a large amount of work is required to select and adapt plant species to suit the very large range of terroir types present.
- Development of sustainable biomass farming systems. Major progress is taking place overseas in this area. While much can be learnt from this work, urgent research is needed to develop sustainable farming systems appropriate to New Zealand terroirs and locally available biomass material.
- Harvesting and transport. There is good potential for competitive innovation in this sector, possibly in co-operation with manufacturers like Claas of Germany, who are specialists in this area.
- Comminution. Additional comminution is often necessary at the plant, which is an area where local expertise can be applied to complement emerging harvesting and transport technologies.
- Biomass processing. Key areas of research presently under way and that warrant on-going support include de-ashing, hydrolysis, drying, product separation and refining, co-processing of biomass with peat, lignite or coal, ultra-fast pyrolysis, solvolysis and thermochemical conversion.



## 3.4 *Municipal Solid Wastes*

Organic wastes from restaurants, hotels, etc. have around 70% moisture content, 5% non-combustibles and a heat value of 5 MJ/kg. Domestic, commercial and industrial rubbish, consisting of packaging, paper, wood scraps, prunings, etc. has around 25% moisture content, 10% non-combustibles and over 13 MJ/kg. Typically, refuse is an even mix of both, and is a crude, unrefined source of biomass fuel. Thermochemical conversion for heat and power generation, or anaerobic digestion to a gaseous fuel, use the same processes as for other forms of biomass, the main difference being the degree of prior separation required.

In order to simplify terminology, municipal solid waste (MSW) is used here to designate both municipal and urban waste. In practice, municipal waste is waste collected by or under the authority of a Local Authority, while urban waste encompasses MSW as well as industrial and commercial wastes collected and disposed of privately. The term MSW is often used in a loose way to designate both types.

MSW has often been presented as a large and often under utilised renewable energy opportunity. This, however, is a gross over simplification which has in a number of countries lead to ineffective and inefficient resource management policies.

MSW is first and foremost, as indicated by its name, a waste issue, that is, the result of industrial societies organised as open systems operating in a predatory mode with respect to their environment. The word “waste”, through Old French *g(u)ast*, comes from the Latin *vastus* which originally meant an uninhabited and uncultivated expanse of land (as in the English *vast*), that nowadays we call wilderness or, more ideologically, the environment. By extension the word meant land that had been rendered uncultivated and uninhabited or sparsely populated as a result of war, or predatory use, which we now call environmental degradation. By further extension, in the eighteenth century, the word waste took as well the meaning of a superfluous and lavish abundance of something and, a century later, the meaning of worthless surplus material (such as the extra sheets of good but now worthless paper left after a printing run). It is only in comparatively recent times, essentially towards the beginning of the industrial revolution, that the word came to mean the useless products of any industrial process from which no further economic value can be generated and that therefore must be rejected somewhere in a waste land, a tip, a dump, or nowadays a sanitary landfill.

Considering MSW as a renewable resource is thus a contradiction in terms. It is renewable, in that more MSW is being produced each year, only in so far as the producing industrial societies are not sustainable and do not function as closed systems integrated with their environment. This contradiction reflects the transitional character of present societies increasingly faced with the need to move away from predatory open systems to something more sustainable. As these changes occur, the meaning of waste will be called to change. A fully integrated society would not produce waste either in the old or industrialised senses. MSW is thus only, at best a transient resource, and a poor one at that since by definition, and this is the core of the problem, waste products are high entropy, negative value products that cost more and more to return safely to the environment or reuse in some way. The key issue is their high entropy (in both energy and order senses) and the huge costs incurred in reordering them to make something valuable out of them.

MSW is not an energy resource per se. As the end stage of very complex and ever changing production and consumption processes, MSW contains nothing in particular and a bit of everything in general. As part of the transition towards more sustainable forms of social life, the processing of MSW is essentially and inherently a fractionation and refining process generating, hopefully, a range of commercial co-products, of which energy, in the form of heat, gas, oil, or power, is only a component, and generally a small component. The fact that, in some countries, incineration is the preferred form of disposal should not mislead. At present, in most cases, incineration is primarily just a form of disposal used as an alternative to landfills when these, still by and large the preferred form, are scarce or difficult to implement. Whatever energy is recovered during the process remains a minor by-product, in thermal and economic terms. The chief purpose of incineration as it is commonly practised remains to shrink the amount of solid waste to be landfilled (down to ashes and slag) and hence to transfer most of the mass that used to be originally landfilled to the atmosphere and to waterways.

The New Zealand Government agreed in 1992 that the Waste Management Policy should be:

- (i) to ensure that, as far as practicable, waste generators should meet the costs of the waste they produce; and

- (ii) to encourage the implementation of the internationally recognised hierarchy of reduction, reuse, recycling, recovery and residual management by all involved in waste generation and management in New Zealand.

The Ministry for the Environment is responsible for the administration of this waste policy and the Waste Work Programme (1995/96) was developed as a result.

Since energy recovery is a component of waste management, albeit a small one, this section attempts to review the potential role and contribution of MSW treatments to a transition towards renewable forms of energy supply. It was drafted in part on the basis of previous work carried out on behalf of the Plastics Foundation for Environmental Research (PFER). The permission granted by PFER to use this material and its assistance in the overall research process is gratefully acknowledged.

### 3.4.1 Technology Review

Due to the complex nature of MSW treatment as presented above, there is no single set of processes that can be easily regrouped and reviewed under a simple “energy technology” label. This section therefore:

- reviews the general field of MSW technologies and positions relevant energy recovery processes within this field;
- focuses on the broad area of incineration and refuse derived fuels (RDF); and
- considers emerging and more sophisticated processes for materials, fuels and energy recovery.

Landfill gas is an adventitious fuel that is a by-product of current landfilling practices. As such, it occurs after MSW has been disposed of in a totally un-renewable way. It is also an extremely low efficiency way of recovering energy from MSW. In the long run, as the use of landfills necessarily dwindle, landfill gas will quickly disappear as a resource. It is thus of an inherently transient nature (see Section 3.6).

#### Overall Status

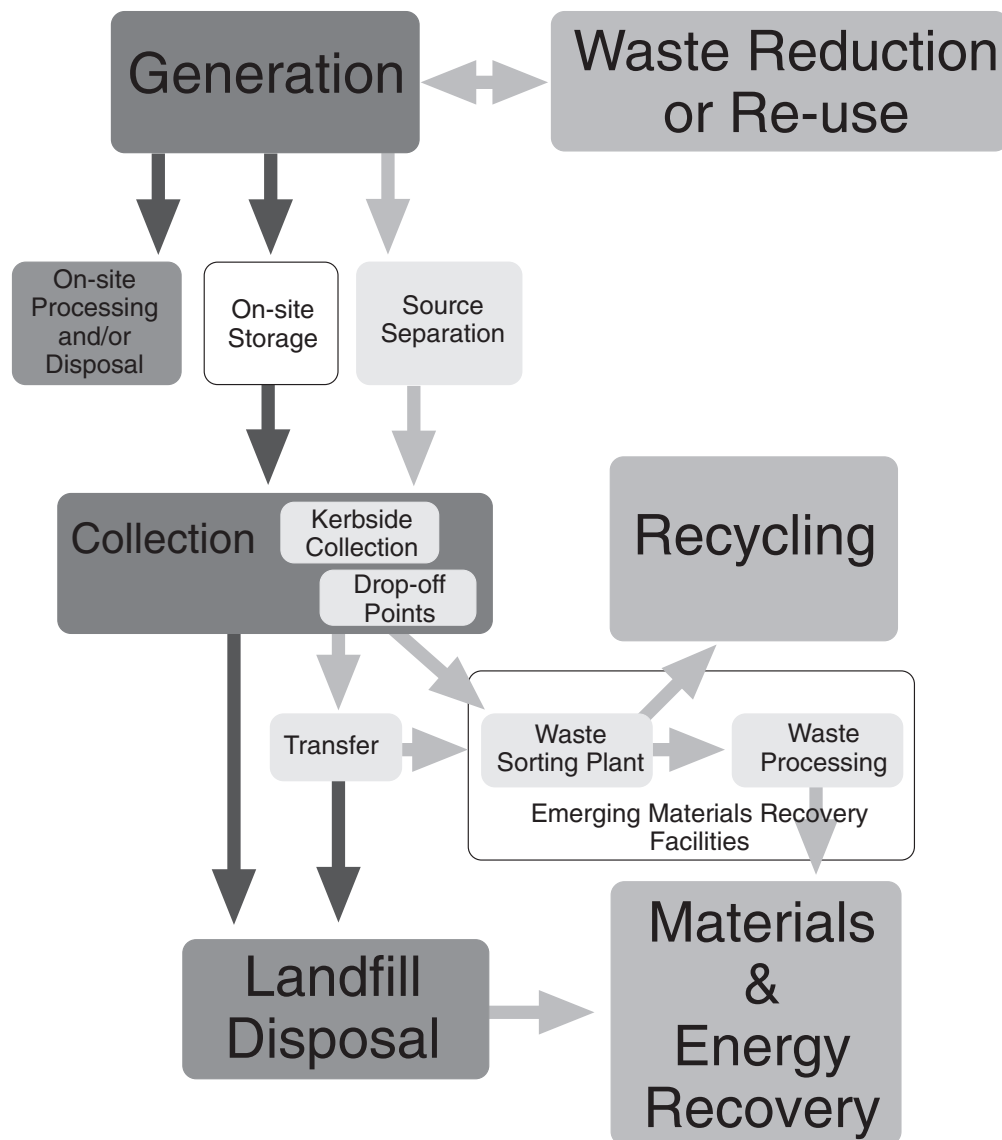
The current status of the MSW collection and processing industrial chains in the main urban centres in New Zealand is presented in Figure 3.7. These chains are in a state of transition from the left of the diagram, and towards the right. At present, over most of the country there is only very marginal on-site processing and source separation, limited recycling of any form, and even less materials recovery, with no energy recovery prior to landfilling. In Auckland, and to a lesser extent Wellington and Christchurch, there is a commercial recycling and materials recovery industry that is emerging from the collection and sorting of traditional paper, glass, metals, and more recently plastics. This budding industry, however, encompasses only a small fraction of the overall MSW stream (less than 10% in most cases).

Overseas, although the situation varies enormously, there is a general, and accelerating, trend away from landfilling and simple recycling, towards fractionation, and materials and energy recovery through what is increasingly called materials recovery facilities (MRFs).

In this respect the difference between recycling and recovery is important. Recycling refers to the separation of some goods out of the MSW stream, say a PET bottle (polyethylene terephthalate), and its recycling into the same type of product (such as second hand PET resin granules to be used to make more PET bottles). Recovery is using the basic materials in the MSW to make a variety of products that can be the same as the original ones or vastly different. For example, plastics (essentially polymers) can be broken down to their constituent monomer molecules and these molecules recovered to make new virgin plastic resins.

The recovery approach offers distinct advantages in terms of:

- flexibility in that several streams of materials can be recovered in the same MRF and the changing composition of the MSW stream can be accommodated;
- significant reductions in labour costs since manual sorting of waste at source, at the kerb-side, and at traditional transfer stations is an inherently inefficient, unpleasant, and expensive form of labour. In



**Figure 3.7: The changing waste collection and processing chain**

particular sorting at source is notoriously unreliable and sorting downstream is also necessary. Recovery involves a single sorting under better controlled conditions; and

- economies of scale and ability to treat the bulk of the MSW stream instead of a small fraction as with current kerb-side recycling schemes.

### **Incineration**

Incineration is a generic term that encompasses a wide range of options that differ markedly in technology, economics and environmental impact. In New Zealand, while a number of incineration schemes have been considered over the last decade, none so far has been found economic relative to landfilling. The two possible exceptions will be reviewed further in Section 3.4.2.

There are three main waste to energy paths:

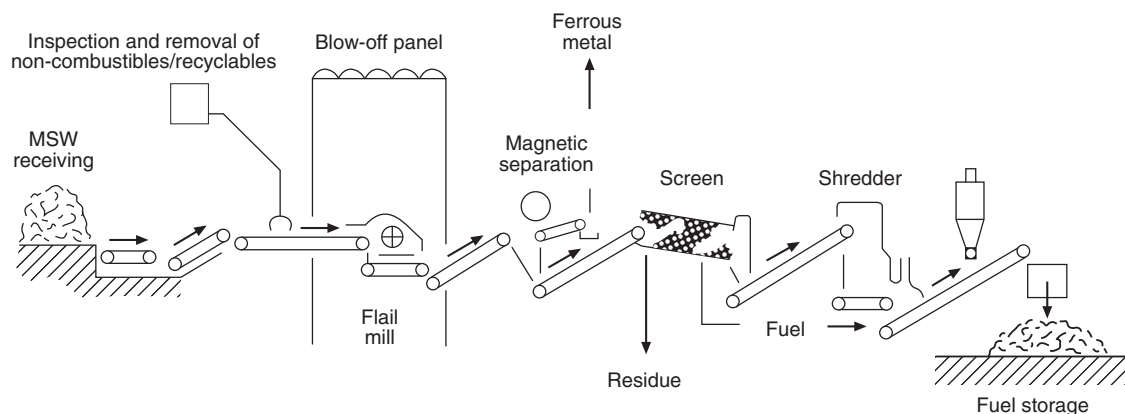
- mass burn of MSW;
- production of more or less refined fuels out of the main waste stream, the RDFs to be burnt in improved incinerators (such as rotary kilns) or via new pyrolysis or gasification techniques; and
- development of new approaches involving the recovery of chemicals such as plastic monomers combined

with gasification, pyrolysis, hydrogenation and/or reforming of the gases and oils produced, as discussed later in this section.

The incinerators required by the mass burn and RDF routes are markedly different, and so are the costs and environmental impacts.

Mass burn is typically a low efficiency approach. While it eliminates large amounts of refuse, little energy is recovered. Typically, MSW has an average heat value of 8 to 12 MJ/kg, as compared with 19 MJ/kg for dry wood, 15 MJ/kg for lignite or 22 MJ/kg for steaming coal. Mixed plastics have an average heat value of 33 MJ/kg. Wet compostable material is in the range of 4 to 6 MJ/kg whilst for comparison, natural gas has a value of about 39 MJ/Nm<sup>3</sup> (56 MJ/kg). In its modern versions, the mass burn process is costly as substantial “end of pipe” technology must be applied for environmental control of emissions. New technology, however, is being developed that improves performance and reduces costs.

Some facilities use some form of sorting to eliminate inerts, putrescibles and produce a more homogeneous refuse derived fuel (Figure 3.8). Several types of RDFs can be made, such as coarse, fluff, powdered or densified, depending on the composition of the refuse, and the technology used. Typically, the MSW, after removal of non-combustibles, is comminuted by a flail mill. A magnetic separator then removes ferrous materials before screening out the larger particles. The remainder is shredded into small particles to make the RDF. RDF is burnt in dedicated boilers or co-fired with another fuel such as coal, lignite, or increasingly biomass (like wood or agricultural residues).



**Figure 3.8: Typical steps to produce RDF**

After a period of stagnation due to high costs and the very negative environmental image of early incinerators characterised by very poor performance, waste incineration is finding increasing support as a means of waste disposal due to:

- fast increasing costs of landfilling due to long transport distances out of large urban areas and environmental and sanitation requirements (in some parts of the US, landfilling costs are well above NZ\$200/t, whereas in New Zealand, they remain low at around \$10 to \$60/t);
- increasing scarcity of suitable landfilling sites in urbanised regions for both geological and political reasons;
- recovery of energy otherwise lost in landfilling;
- cynicism with respect to the huge cost of some separate collection and manual recycling schemes.

For each proponent, however, there seems to be at least one opponent of incineration as a generic approach. The concerns most often quoted are:

- increasing costs of incineration technology due to ever stringent environmental standards. In Europe or Japan incineration costs are often above NZ\$200/t; a typical incineration facility costs NZ\$9,000 per installed kW of capacity, whereas a combined cycle power generation plant would cost about a tenth of that value;

- uncertainty and risks incurred with the large investments required, in the face of frequently changing regulations;
- environmental impacts themselves, in particular concerns with dioxins and furans, acid gas, heavy metal emissions, and more recently CO<sub>2</sub> emissions resulting from the combustion of fossil materials;
- waste of resources that are lost just as much through some forms of incineration as with landfilling; and
- low energy efficiency and poor energy recovery.

Suitable sites for landfilling are becoming scarce, in others environmental conditions make most mass burn incineration schemes unsuitable.

Many mass burn schemes that were started decades ago could not be initiated nowadays because of far more stringent environmental regulations. Furthermore, there is no single incineration technology to be considered but a large array of technologies that can be combined in different ways, which makes comparisons somewhat difficult. However, within this complex array of conflicting views and approaches, it is possible to single out a major trend towards an emerging range of technologies reflecting changing waste management policies and strategies world-wide.

Mass burn remains an important approach. Table 3.8 presents an overview of incineration facilities in a selection of industrialised countries. In many countries, most older facilities are simple incinerators without any substantial heat recovery. In Japan, for example, while most plants are said to recover some energy, in effect only about 35% of schemes are truly “waste to energy”. In the USA, 75% of existing facilities recover the heat, but 80% are of low efficiency mass burn or modular types. In most countries using high levels of incineration schemes, the high capital investment cost is subsidised by the state.

Country	% MSW Incinerated	No. of Plants	% Waste to Energy
Canada	9	17	7
USA	17	168	75
Japan	80	1900	35
Sweden	55	23	86
Denmark	65	38	90
France	42	170	67
Netherlands	40	12	72
Germany	35	47	n/a
Switzerland	80	n/a	n/a
Italy	18	94	21
Spain	6	22	61
UK	7	30	33

(Sources: OECD, Hester and Harrison, 1994)

**Table 3.8: Incineration facilities in selected countries**

An analysis of technological trends and relative economics shows that future development of mass burn is likely to be limited to extreme situations.

A case in point is the well publicised new mass burn SELCHP facility in South East London that was commissioned in early 1994 (Wheatley and Hedgecock, 1993). This facility is designed to treat 420,000 t of MSW per year with a generation capacity of 30 MWe. This is vividly illustrative of the low efficiency of mass burn, and is only economically viable because of very advantageous power purchase rates under the NFFO system (Non-Fossil Fuel Obligation, a UK scheme that substantially subsidises power generation from renewable energy sources). In addition to power generation, the SELCHP scheme is intended to supply heat to 7500 households and schools by way of a district heating scheme. The combined heat and power operation (CHP) is intended to be implemented when the current NFFO contract expires.

This case demonstrates the constraints and limits of most mass burn technology. It is the first incineration facility to have been built for years in Europe. In the UK, there are some 30 mass burn incinerators with only five designed to recover energy. Most were built in the 1960s and 1970s, and will have to close in the near future because they no longer comply with EU environmental legislation.

A similar situation also prevails on the European continent where some facilities, such as the Zindorf incineration plant in Bavaria, Germany, have to be retrofitted to improve combustion processes and cleaning of flue gases. The Zindorf retrofit will cost NZ\$9 million for a 28,000 t/year capacity, an investment of \$321/t of capacity (Jungmann and Haltiner, 1994).

The SELCHP facility is viable only because of its large scale (420,000 t/y) and because the large NFFO subsidy guarantees it about NZ 20c/kWh generated until 1998 (during the most financially vulnerable period of its life), and because it has the prospect of extending into a cogeneration operation, which is only viable in areas of very dense urbanisation (Taylor, 1994). Such a facility would not be viable in New Zealand under present or expected future conditions (too large investment cost, much lower price of electricity, no viable market for district heating).

The limitations of mass burn technology are highlighted further in the literature survey and interviews conducted in Europe and America for the purpose of a recent study of the potential of plastic waste to energy in the Auckland Region (Arnoux, 1995). Hester and Harrison (1994) considered MSW mass burn requires to process at least 200,000 t/y to be viable. Capital investment costs are in the order of \$675/t of installed capacity to meet European Union standards. A doubling of capacity is estimated to lead to a 26% reduction in unit cost.

Present trends indicate a move away from single solutions (such as mass burn) towards the integration of more advanced incineration technology within overall waste management strategies, based on setting priorities for waste treatment methods. These include waste minimisation, recycling, materials recovery, composting, biogas production, energy recovery through RDFs, and residual landfilling.

A number of American studies in the 1980s highlighted the serious environmental hazards created by many existing incineration schemes. The conclusions of such studies are well summarised in *An Environmental Review of Incineration Technologies* (1986, ILSR, Washington), which stressed that “due to known health risks from air, soil and water pollution, it is essential for MSW management facilities to:

- minimise the amount of unseparated and moist waste incinerated;
- incinerate remaining fractions as a dry, low-ash, homogeneous fuel using commercially available incineration and pollution control technologies; and
- avoid incineration “wherever possible.”

This approach favours the integration of incineration within a range of complementary approaches. In the process, mass burn incineration tends to be replaced by more specific and efficient techniques such as RDF incineration, gasification or pyrolysis.

In practically all cases, the arguments put forward in favour of mass burn or incineration of poorly prepared RDFs, are presented by reference to landfilling rather than to fully integrated waste management strategies (Freiesleben, 1993). Invariably, all of the arguments presented in favour of mass burn apply even more strongly to the newer, more specific and more efficient methods such as gasification or pyrolysis. Advantages include:

- reduction by up to 90% of the volume of waste to be landfilled;
- sterilisation of waste;
- conversion of waste to CO<sub>2</sub> rather than CH<sub>4</sub> (as tends to occur in landfills);
- concentration and safe disposal of heavy metals;
- reduction of dioxin emissions to negligible levels versus much higher levels in uncontrolled fires at landfills;



- mineralisation of inorganics into inert compounds and production of construction materials; and
- energy recovery.

All of the above advantages are even stronger in the case of higher efficiency RDF combustion combined with recycling and materials recovery. In addition, straight MSW incineration is of low thermal efficiency compared with an efficient burn with dry RDFs.

The attitudinal and policy trend towards integration of incineration within a range of complementary approaches is paralleled with a technological evolution in the same direction, as illustrated in the *Directory of Waste Utilisation Technologies In Europe and the US*, (1989, ILSR, Washington). The examples of technology implementation reviewed in this directory demonstrate a trend towards materials and energy recovery through mixed waste processing to complement recycling. The prime incineration technologies reviewed are pyrolysis/gasification and fluidised bed combustors.

Technology is moving fast in this area with a number of new approaches or renewed technologies. The EnerTech process currently under demonstration in the US, for example, is based on a pre-treatment of MSW in water slurry form to facilitate the removal of recyclables (Energy Conservation News, 1994). The slurry is then subjected to high pressure and temperature conditions and partial dewatering to turn it into a higher calorific value RDF amenable to gasification for combustion in a high pressure steam boiler or to power a gas turbine. If successfully demonstrated this process, albeit expensive, will have very low pollution levels and significantly higher thermal efficiency than mass burns.

The WABIO process developed by Ecoenergy Oy, Espoo, Finland, provides another example. It is a biothermal waste treatment. Waste is pre-treated and divided into organic and combustion fractions. The organic fraction is degraded into biogas and compost matter. The RDF is burned in a specially designed fluidized bed boiler unit. The temperature is kept below 900°C to avoid the formation of thermal NO<sub>x</sub> and of dangerous slagging compounds that could threaten the life of the boiler. From one tonne of municipal waste, 535 kg of RDF is produced.

The VALORGA process, developed in France, uses a similar approach. MSW is shredded and sorted mechanically (with manual polishing) to recover glass, metals, plastics, inerts such as sand and gravel, and remove sources of toxic compounds such as batteries. The remaining fractions (including hospital waste) are separated into a dry RDF that is directed to a rocking kiln for steam raising and base load power generation, while the fermentescibles are sent to a proprietary, high solids (above 45% solids), computer controlled, high yield methane digester. The methane is used to produce peak load power. The organic residues are composted to produce a sterile high quality soil conditioner. A plant processing 120,000 t/y of fermentescibles could generate 31 GWh of power from the methane produced and 57,000 t of soil conditioner

The trend in favour of such new energy technology integrated within an overall waste management strategy focusing on materials and energy recovery is illustrated further by the recently announced French government's plan to phase down landfills and develop up to 150 new MSW conversion facilities in the first decade of the next century.

### ***Packaging and Waste Incineration***

Within the general field of energy recovery from waste, packaging and waste incineration remain particularly controversial topics. There is currently no commercial technology for the combustion of separated mixed plastics. The debate centres essentially on the merits of co-firing plastic waste with other products.

For example, the Association of Plastics Manufacturers in Europe has recently conducted tests at the Würzburg 20 t/h incinerator (Germany) by blending various amount of plastic to the household waste processed at this facility. As could be expected, the more plastic incinerated the more heat and the more electricity produced, with reduced airborne pollution from un-burnt particles and compounds (Coghlan, 1994; Frankenhaeuser, et al., 1992).

Burning the fraction of plastics in MSW that is so dirty or low in quality as to make it uneconomic to recycle can be beneficial. However, it is also important to note that the situation is different for existing incinerators and new schemes. While burning some plastics can marginally improve the low efficiency of an existing mass



burn, in most cases this solution will be inferior to the recovery of materials, including plastic monomers, production, and efficient combustion of a dry RDF.

In a related way, the reduction of the proportion of plastics in MSW that results from successful minimisation, recycling and recovery schemes, can affect the already poor efficiency of mass burn incinerators. In parts of Europe where incinerators are old, plastics are a necessary fuel component for their economic operation (Mark, 1992). This is not the case, however, with up-to-date technology discussed in Section 3.5.1.

A related area of experimentation, concerns the production of special RDFs where plastics are an important component, along with paper and board. These packaging derived fuels (PDF) are of particular relevance in Germany because of the Green Dot system of returning packaging materials to manufacturers. Except for gasifiers, there is no economically viable and well demonstrated technology to burn PDFs on their own. Most work concerns co-firing with other fuels, mostly coals, peat or wood. The European Centre for Plastic in the Environment has recently conducted a review of such work (Frankenhaeuser, 1993). It shows clearly the technical feasibility of co-firing up to 20% of the thermal feed, the balance being fossil fuels. In a number of cases PDFs assist in improving emission levels. This approach, however, is only economically feasible on a large scale and in areas where communities or nation states are prepared to pay for the very high costs of mass source separation (in the order of NZ\$300 per tonne or more) and where existing solid fossil fuel based thermal plant are available locally to minimise high transport cost of the PDF.

### ***Development of Chemicals, Liquid and Gaseous Fuels Recovery***

In recent years, faced with growing concerns about the serious difficulties and high cost encountered by most recycling schemes, a growing number of chemical industry firms and research organisations have turned their attention to the recovery of organic chemicals and gaseous and liquid fuels from the waste stream. Plastic wastes are of particular concern since they represent 5% to 12% of most MSW streams, are conspicuous, and are derived from oil and natural gas, two non-renewable resources.

Much of the non-biomass derived chemicals in MSW are in polymeric form. A substantial component of the R&D effort is to break these down to revert to the basic monomers, the “building blocks” from which they are made. Polyethylene in a polymer, for example, is made from chains of monomer ethylene molecules. There is an economic component in this move as recycled plastics will attract a price of less than \$100 while recovered monomers from which virgin polymers can be made can fetch \$300.

In the US, existing regulations make it difficult to recycle non-virgin resins in food or beverage containers. This has led to a three layer PET bottle with only the middle layer being recycled. Further, in many instances the recycling of plastics incurs an environmental penalty in the form of urban air pollution and greenhouse gases released by separate collection vehicles whose driving cycles involve frequent stops and start. More generally, experience shows that only a relatively small fraction of organic chemicals in MSW can be recovered (at great cost) through kerb-side or drop off collection points.

The rationale of the chemical industry approach is to close the loop at the molecular level rather than at the resin or polymeric level. This presents a number of advantages:

- use of mixed waste, with no need for expensive sorting;
- a relatively high level of impurities in the feedstock can be tolerated without harming the recovered material;
- for some processes, the recovered materials have a guaranteed market;
- the higher value of the recovered materials leads to a reduced processing fee (the equivalent of the current “tipping fee” or landfill gate fee).

The processes currently being developed and/or demonstrated include gasification, oil substitution and monomer recovery. In all cases, the aim is to crack polymers down to some simpler molecular component. The differences are in:

- the extent of the cracking;

- the nature of the resulting materials (which may be more akin to an oil or gas fuel or be strictly base materials for the production of new virgin resins);
- the economies of scale and critical mass required in terms of mixed plastic collection;
- investment and operation costs; and
- tolerance of impurities.

### ***The Gasification Approach***

Over the last two decades much research has been devoted to a wide range of gasification technologies with a view to transform coal or biomass into more useable products or to eliminate waste and residues such as MSW or RDFs. The Texaco Gasification Process is an example of a proven large scale gasification technology being actively marketed for a wide range of applications, including MSW processing (Curran and Simonsen, 1993; Curran, et al., 1992).

The core of the process is a pressurised gasifier operating at 20 to 80 bar, 1,200 to 1,500 °C, and using an oxygen supply. The product is synthesis gas for which the potential use could be power generation, say in a combined cycle power plant, large scale cogeneration for process heat and power production, or chemical synthesis of new polymer. In Germany, Veba-Oel uses a similar gasification approach to produce an oil substitute (40,000t/y) followed by hydrogenation at 300 bar in its oil refinery. The process is apparently affected by a poor energy balance and negative public perception of it as an energy source rather than a materials recovery operation.

Texaco consider that a 100 tonne per day plant (that is about 30,000 t/year of pre-sorted waste) would cost about \$40 million (without the ancillaries and downstream processing plant) and would be economic in the USA.

Such an option is not feasible in New Zealand, even in Auckland, because the critical mass for waste feedstock supply could not be reached in the foreseeable future, and because gasification needs to be attached to a large chemical processing plant to make it viable. The synthesis gas produced has a low heat value of around 4-5 MJ/Nm<sup>3</sup>. At current and expected power prices, a stand-alone power plant or even cogeneration plant would not be viable.

### ***Production of Oil Substitutes***

A number of approaches treat organic waste less severely than the Texaco approach to produce what are effectively oil substitutes through various pyrolytic or cracking processes. Examples of such processes include the Conrad and Toshiba processes.

In the US (Oregon) the Conrad process was used to process urban waste to recover material from chemical polymers. This was a small scale unit processing 5000 t per year through a rotary kiln and a liming stage to produce an oil-like product. The process has been banned because the oil substitute was considered by the authorities as an energy product, and as such the overall process was not achieving the required level of material recovery.

The Toshiba process is at the pilot stage, as reported in *Plastics in the Environment*, August 1994. The plant has a capacity of 250 kg/h over an 11 hour work day. It processes mixed plastics from Toshiba's factories in Japan to produce a range of oil substitutes. The process is essentially a series of cracking units. A high density alkaline solution is used to neutralise the chlorine (e.g. from PVC) and some of the additives that resist heat cracking. A second high pressure cracking unit boosts reclamation further. No economic data is yet available. Other Japanese companies are pursuing similar routes.

### ***Monomer Recovery***

#### ***The BASF Approach***

In the context of the German policies for recycling and materials recovery from packaging, BASF Aktiengesellschaft and OTTO Kunststoffservice GmbH have submitted a tender in 1994 to treat 300,000 t of

mixed plastic waste per year. BASF expect to convert 15% to 20% of its plastic waste into new products and the balance, of soiled and non-homogenous products, to monomer and energy recovery.

In preparation for the implementation of this scheme a 15,000 t pilot plant was commissioned in 1995 at a cost of about \$40 million. BASF expects the full scale plant to cost about \$300 million and to commission it in 1996.

The process treats uncleaned mixed plastics. The chlorine recovered from plastics like PVC is recycled into its hydrochloric acid works. The high boiling point organic residues are gasified to produce a synthesis gas. Final inorganic residues, less than 5% of the processed plastics, are landfilled. The main outputs are naphtha-like products which are used in BASF's complex to produce plastic monomers.

The process yields 90% recovered materials by weight. It is a two stage approach where plastics are first melted (300 to 400 °C) to recover the chlorine and then pass into a second higher temperature stage (400°C to 500°C) with associated distillation in which the polymers are cracked and the fraction separated.

While the main products recovered from the cracking of plastics could be used by BASF's 560,000 t/year naphtha processing operation, this will only take place when that route adds the most value. BASF could also sell the products as a diesel-like fuel. This indicates that the naphtha-like materials might have some quality problems. In its present state the technology is not fully differentiated as strictly materials recovery.

It is also important to note that BASF's approach is only viable with gate fees of about \$325/t. Because of the critical mass required and processing costs, this process would not be viable in New Zealand. Other German companies have similar units planned.

### *The Battelle Approach*

The Battelle Research Institute, Columbus, Ohio, a non-profit research organisation employing some 9000 scientists, is presently developing a process specifically targeted at monomer recovery from mixed plastic waste.

Its small pilot unit of 10 kg/h has shown promising results. Based on the average composition of mixed plastic waste in the US, the main monomers produced are ethylene (40%) and methane (27%). The ethylene can be produced for about 6.6 cents/kg (including capital related costs) in a 450 t/day plant (about 150,000 t/year). Conversions of 60% have been achieved so far and are expected to increase with refinements currently being designed.

This option is economically more attractive than the other processes reviewed above and would become more so if it could be scaled down to around 15,000 t/year, since the main product is a chemical feedstock gas. However, the process has limited application in New Zealand where the main large scale chemical plants are far away from the main urban centres.

### *The BP Approach*

This is a one stage process that appears simpler, less capital intensive and gentler than most other processes reviewed above, except perhaps for the Battelle process.

The core of the process is a fluidised bed where polymers such as granulated mixed plastic waste are heated at 400°C to 600°C. The gases and vapours then go through a heat exchanger and to a condensation unit (Troussier, 1994). The condensed wax-like fraction is equivalent to a naphtha. It can be stored, exported, and processed in a refinery via steam cracking (at the rate of about 20% wax to 80% new naphtha). One of the key advantages of this process is that the polymer cracking plant does not need to be attached to a large plant for downstream processing.

The residual gases (equivalent to 10% of the input plastics) are compressed and preheated through the heat exchanger by the gases and vapours coming from the fluidised bed. Some of the gas is used in a burner to further heat the residual gases to fluid bed temperature. These gases are then used to maintain the bed in a fluidised state.

In this process, the waste products are shredded to 0.5 - 2 cm and prewashed. Up to 5% impurities can be tolerated. Up to 2% PVC can be processed directly. Beyond this level, a dechlorination stage must be added

(at 300°C) before the waste feedstock can be fed into the fluidised bed. Fines and heavy metals entrained with the gases are trapped with cyclones. Overall the resulting product is of very high quality, with very low levels of contaminant, something many of the other competing processes do not achieve with the same economics.

The process yields 90% naphtha-like wax, which is currently worth \$360/t on world markets. A pilot plant is in operation in Scotland. BP consider a full scale plant would treat 18,000 to 25,000 t/year and would cost \$40 to 60 million. Under European conditions, the internal rate of return is estimated at 10% over the life of the plant with a gate fee of \$200 - \$300 /t.

While this is far too expensive under New Zealand economic conditions, this approach, along with Battelle's, is the most promising of overseas developments. Provided economics could be improved and plant scale reduced, the approach could provide an elegant way of recovering monomers from separately collected plastics, and from additional sources such as car wrecking, scraps from supermarkets, and industry sources. Collection in the Auckland region could easily reach the volume of pre-sorted waste required for a 10,000 t plant in the medium term.

## The Converttech Approach

Convertech technology is directed at the processing of biomass into valuable products such as chemicals, reconstituted wood products like panel boards, heat and power. As such it is not specifically designed to handle mixed waste. In the long run, in the field of waste management, its main application is in the treatment of MSW to produce a dry, cleaner burning RDF.

Convertech could potentially offer a solution to monomer recovery that could prove more competitive than the overseas approaches reviewed above. At this stage the core Convertech technology has reached the pre-commercialisation stage. The potential chemicals and fuels recovery application is only at the preliminary concept stage.

In essence part of the core Converttech process for biomass involves venting the volatiles produced by the preheating of the biomass. Through steam entrained distillation it is possible to recover the volatile products either as a fuel for process heat or as valuable products, such as essential oils from Eucalyptus biomass.

In the Conwertech process, biomass fed into the plant as particulate matter is entrained at about 20 m/s in a steam atmosphere, at pressures of up to 30 bar and temperatures in the 200-300 °C range. After screening for metals, glass, etc., finely shredded MSW, being 75% wet biomass, could be easily processed in the same way.

By raising the temperature in one of the process modules to about 500°C, the same basic volatile venting process as described above could be used to extract gases and vapours coming from the organic polymer fraction of MSW. In this way monomer recovery could be achieved without extensive preliminary sorting of the organic MSW stream.

The steam entrained gases could then be processed to recover the naphtha-like wax, while the shredded MSW could be processed further in the superheated steam multiple effect drying stage of the Convertech system to be dried into a stable RDF.

Another set of issues is related to the heavy metal content of MSW. One of the merits of the BP process is to produce a naphtha that is very low in heavy metals. It is not yet known to what extent an approach based on the Convertech process could lead to low heavy metal levels.

The Convertech process can be implemented at relatively small scale levels down to 2 t/hour, that is about 15,000 t of MSW per year, or 1,000 t of polymer waste contained in such MSW.

On the basis of preliminary estimates established for power generation from biomass, a Convertech plant processing MSW at the rate of 20 t/hour and equipped to recover about 9,000 t of monomers per year, while also generating power from the RDF produced, would have the following financial characteristics:

- investment cost \$54 million;
- gate fee for the MSW \$15/wet tonne (less than half the current rate in Auckland);

- average cost of power produced      2-3 cents/kWh;
- average price of power produced      8 cents/kWh (over 20 year life span of the plant);
- sale price of naphtha                      \$360/t;
- internal rate of return                      18% (over 20 year life span of plant, with 75% borrowed capital at 9% interest).

Although the above figures are indicative only, they look sufficiently promising to warrant further investigation. In the above estimate, the Convertech process has been assumed to have been integrated with an efficient incineration unit. In practice the Convertech process could be used as a front-end (monomer recovery, drying) to a wide range of RDF combustion units.

In this context and in a long term perspective, mention must be made of current trends in R&D on both biomass and MSW processing which show a renewed interest in fast pyrolysis and solvolysis approaches. Fast pyrolysis refers to the heat treatment of particulate organic matter at 300°C to 1300°C under steam or other non oxidising gases at pressures ranging from atmospheric to above 30 bar to produce pyrolytic oils and/or medium to high energy value gases. Solvolysis refers to the use of organic solvents at 200°C to 300°C to dissolve the solids into an oil-like product ("bio-oil"). Such products offer the prospect of gas turbine firing with thermal efficiencies of over 40%, being substantially higher than those presently achieved with steam turbines powered with current RDF combustors/boilers (typically 25%).

Both approaches can be effectively and efficiently implemented with the core Convertech process. In this domain Convertech has recently filed a patent application for a novel ultra-fast pyrolytic nozzle reactor that is expected to achieve high conversion efficiencies to produce either a substitute natural gas (SNG) or a range of oils from organic feedstocks such as biomass, MSW, peat, and lignite. Compared with comparable overseas processes the Convertech unit is expected to be economic at relatively low scale (such as 10 to 20 odt/h).

These New Zealand and overseas developments also points at a long term perspective where the waste to energy route no longer leads exclusively to combined heat and power generation. With catalytic hydrogenation and reforming, pyrolytic and "bio-oils" can also lead to transport fuels.

### 3.4.2 The New Zealand Experience

New Zealand has very little practical experience with MSW to energy. There are presently three schemes involving incineration technology in the Auckland Region. One is in operation and is purely a disposal facility. The other two are at the design and promotion stage. They are:

- airport incinerator;
- proposed gasification and materials recovery ISIS scheme at Waitakere City; and
- proposed Olivine MSW incineration scheme for a large capacity incinerator (300,000 t/year).

#### **Auckland Airport Incinerator**

The Airport Incinerator is located next to Auckland Airport. While easily accessible by road, the incinerator is designed to process essentially airport waste that is supplied directly to it. It is a new state-of-the-art quarantine waste incinerator. The equipment is a Basic 2500, with a nominal rating of 45 t/day (15,000 t/y), designed by Basic Environmental Engineering Inc, USA. It is a tried and proven design which has won several awards for its environmental features and is capable of handling the wide range of waste produced at the airport or delivered by visiting planes.

Owing to the need to protect New Zealand's fauna and flora, by law all airplane and airport waste must be incinerated. The resulting waste stream is a very wet combination of organic waste (such as food left-overs), mixed plastics, papers, glass and tins, which requires an additional fuel, here being natural gas.

At present this incinerator does not recover energy and is substantially under-utilised. Given the high charge out rates set up at the inception of the venture, international airlines tend to prefer disposing of their waste



overseas, in particular in Sydney. This facility could not be transformed into an energy operation without a large capital investment that would be totally uneconomic.

### **ISIS**

The Waitakere Council recently selected ISIS as its preferred waste gasification technology. The ISIS approach is to progressively combine a range of technologies to develop an integrated energy and materials recovery operation revolving around the gasification and combustion of RDF. The aim of ISIS is to eventually achieve total use of the MSW stream and transform all components into commercial products. In this perspective, for example, the CO<sub>2</sub> produced by the combustion process would be used in glasshouses to boost biomass production. The Council considered that in the long term, some form of waste processing to recover materials and energy will be required and that such processing will be increasingly competitive with landfilling. The Council also expects landfilling costs to increase substantially in the medium term as a result of the oligopolistic position of present commercial operators.

The initial stage would be a pilot plant aimed at demonstrating the RDF gasification and combustion process. A small pilot is already in operation on Waiheke Island. The gasification and burner parts are very efficient reaching temperatures of up to 1,150°C that are high enough to eliminate toxic components. The plant is designed to have no significant environmentally harmful emissions.

The plant capacity will be in the range of 15,000 to 18,000 t of MSW per year. It will operate 24 h per day and have a capacity of about 6 MWe plus a certain amount of process heat supplied to other nearby industries.

The heat and power output could be significantly boosted with the inclusion of a preliminary RDF preparation stage involving a thermodynamically efficient form of drying. As noted earlier, MSW is about 40% to 50% wet and power generation with such wet fuels leads to poor thermal efficiency in the 15% to 20% range.

The ISIS operation could be complemented with a composting facility to process part of the biomass coming from gardens and parks waste. Eventually the approach could involve vitrification of residues and ashes to manufacture building and/or construction materials. It would also include sorting and materials recovery at the front end, if and when these operations become economic enough to recover items such as metals, glass, etc.

### **Olivine**

Prior to Waitakere selecting ISIS, there had been a broader exercise involving most city councils in the Auckland Region. This followed the regional restructuring of waste management that took place in the early 90s, and the transfer of much waste management responsibility to city councils. Each city council evaluated commercial proposals in terms of its own circumstances. Auckland City Council selected Olivine NZ Ltd at the conclusion of a lengthy and careful analysis.

The Olivine approach, like ISIS, involves incineration of MSW for power generation in an environmentally sound way. The Olivine technology, however, is at a more advanced stage of development and could be implemented on a larger scale in a shorter time frame.

Olivine's successful proposal is to use the mothballed Meremere Power Station site and redevelop it for a large scale "Waste to Energy" and "Toxic Waste to Materials" operation. The project is not dependent on the availability of Meremere and could be developed on a new site.

Meremere is an old coal-fired power station partly refurbished some 8 years ago. Being an old design, its thermal efficiency is low (around 28%), and being coal-fired, this means that if used as is, it would emit a substantial amount of CO<sub>2</sub>.

Olivine's plan is to partly refurbish the Meremere plant, restart it temporarily on coal, then build next to it a set of five RDF burners and new boiler assembly to substitute for the coal ones and feed the steam into the existing steam turbine and power generation plant. In this way, there would be a progressive substitution of MSW for coal with a range of environmental benefits. With 180 MW, expandable to 330 MW, this project's capacity is substantial. The WEL energy group and Ngati Naho, a sub-tribe of the Tainui, joined the Olivine NZ consortium in mid-1996 to further evaluate the project. A decision is expected by the end of 1996.

The Olivine Corporation US owns the only commercial deposit world-wide of the mineral olivine that is suitable for the manufacture of refractory combustion chambers. It can withstand high temperatures with low and uniform expansion and contraction. The unique properties of the mineral enables Olivine to design furnaces from 0.25 t to 60 t/h with long residence time, high turbulence and temperatures that position them among the cleanest burning in the world. Olivine NZ has designed a series of innovative modifications to old power stations that enables the parallel use of coal, MSW and natural gas.

Since about 75% of MSW is derived from biomass, 75% of the carbon it contains is “current cycle” carbon, as opposed to carbon derived from fossil fuels. Auckland refuse has a calorific value of about 10 GJ/t. Recovering this energy, along with some of the fossil energy embodied in the MSW stream, is far more efficient in terms of resource management than the burning of more coal or natural gas. It also leads to a very significant reduction in greenhouse gas emissions compared with additional generation capacity built on gas.

Olivine NZ plans to extract compostible waste at strategically located transfer stations in the Auckland region and the Waikato, and use the railway network to transport the resulting RDF to the power generation site. Overall the estimates Olivine has tendered, and that were audited by Auckland City Council, indicate that the project would be competitive with landfilling. It would create 140 jobs and revitalise the Meremere village. Other sites are also being considered

### ***Prospects for 2005***

The ISIS and Olivine experiences are illustrative of the institutional difficulties and uncertainties attached to the development of waste to energy schemes. While these technologies appear promising, their implementation in New Zealand remains highly uncertain. Under present political and economic circumstances marked with uncertainties as to the future operation of the wholesale power market, waste management policies at the local and central government level, as well as the relatively high geographical dispersion of MSW production, it is unlikely that mass burn, RDF or any other form of waste to energy facility will be developed before the turn of the century. Eventually, some scheme of the Olivine type can be expected, with or without monomer and materials recovery, to be implemented in the Auckland region and later in the greater Wellington and Christchurch regions. The overall potential is of the order of 500 MWe to 600 MWe of installed capacity. Only about a third of this potential is likely to be installed by 2005.

### ***3.4.3 Current Resource and Potential***

Knowledge of the MSW stream in New Zealand can be characterised as “an informed lack of data”. Value estimates of MSW into landfills range from 1.1 to 2.5 million tonnes/year. The waste streams of the main urban centres have been analysed and reanalysed but never in a fully integrated way, and never in a way that could accommodate the data requirements of emerging new technologies and within a long term development perspective. In many respects, the institutional restructuring that has occurred over the last three years has made matters worse by fragmenting data collection efforts. This comes at a time when the effects of the economic crisis, technological change, and the early results of waste minimisation and recycling policies combine to significantly modify both the total volume and composition of waste and do so differently in various parts of the country and of each region.

In 1992, the Ministry for the Environment initiated the development of a waste analysis protocol as an attempt to establish coherence among data from various sources, and to ensure that data would be collected in a way that would enable the consideration of long term alternative options, such as recycling, energy and materials recovery. The new protocol is now being implemented by most city councils in the country, but has not yet been used long enough for useful time series data to become available. At present, the new system only offers a snap shot at a given point in time. Given the fast changing composition of a number of waste streams, and rapid technological change in the waste management sector, a large amount of guess work based on interpolation of a range of surveys will remain necessary for the next five years at least.

Overall, if 1.225 million tonnes/year of MSW is assumed, the New Zealand population generates between 0.5 kg and 1.8 kg/head/day of waste with an energy value of 2-6 PJ. This is less than in the US (over 2 kg/head/day) but marginally more than in Europe (around 1 kg/head/day) Waste streams vary significantly however, between urban centres, between regions, seasonally, and over the years.



In the absence of sufficiently reliable data for the whole country, data from the Auckland and Christchurch regions is reviewed below to illustrate issues and problems.

### ***Evolution of The Overall Waste Stream***

Figure 3.9 presents the evolution of the overall waste stream in recent years in the Auckland region. Waste generation is directly linked to economic growth (or recession) but with a certain asymmetrical lag. That is, waste generation starts declining some time after a recession has been firmly established, but starts increasing again very soon after the economy recovers.

The economic recovery has increased the waste stream by 17% in 1994 despite the waste minimisation campaigns developed by all the city councils in the region. This rate of growth is faster than in pre-recession and pre-waste minimisation times. It illustrates the difficulties current waste minimisation policies are faced with and highlights the probable need for an altering of strategies in years to come, as new technology develops.

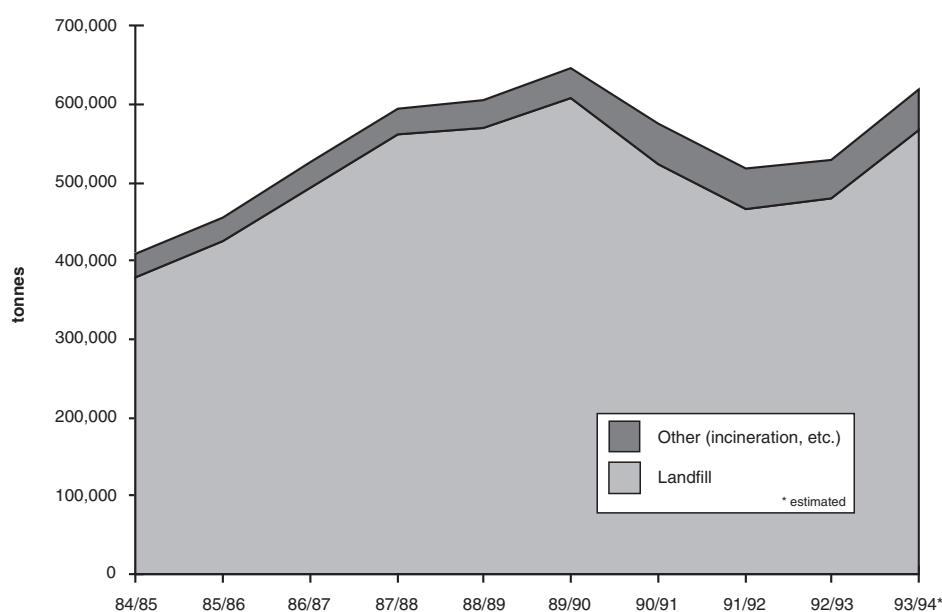
### ***Composition of the Waste Stream***

An indication of the origin of MSW streams in a large urban centre like the Auckland region in 1994 is shown in Table 3.9. More precise data is becoming available from the waste surveys based on Ministry for the Environment's waste analysis protocol. For example, Figure 3.10 presents the composition of the MSW stream in Christchurch in 1992 derived from the first pioneering survey carried out using the waste analysis protocol. It was found that the data was not detailed enough for proper evaluation and more cross-analysis was necessary.

Non biomass derived organics (derived from oil and natural gas resources) represented about 7.3% by weight of the total MSW. It is high in calorific value and non renewable. Beside the biomass derived fraction it is the most important organic fraction from a materials and energy recovery point of view. In Auckland this fraction was 4% in 1977, and 6% in 1988. Wellington figures increased from 3.1% in 1979 to 5.3% in 1988. The current proportion of such waste in the Auckland region is estimated to be between 7% and 8%. In other words, the non renewable high calorific content of MSW has increased to the levels of other industrialised countries (8% and above).

About 50% of this waste stream is packaging, and only a very modest proportion of it is presently recycled (estimated at 3,000 t/y for the whole Auckland region against a total landfilled amount of about 60,000 t).

Figure 3.11 illustrates the low level of seasonal variability in an urban centre like Christchurch. Some smaller centres are expected to show much greater variation.



**Figure 3.9: Evolution of total Auckland waste stream**

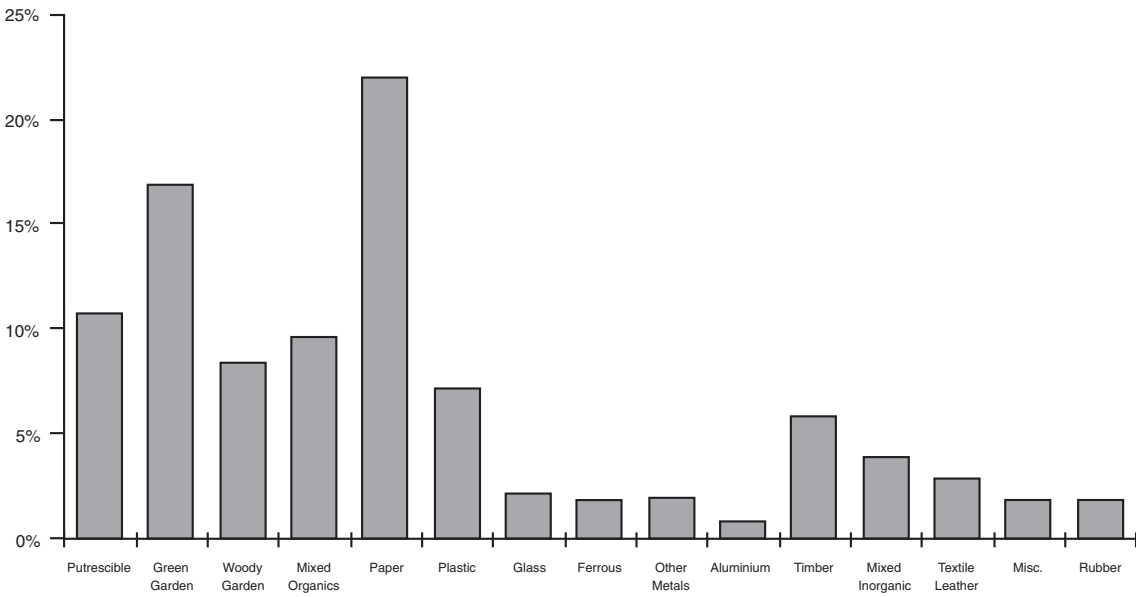


Figure 3.10: Composition of the refuse stream in Christchurch

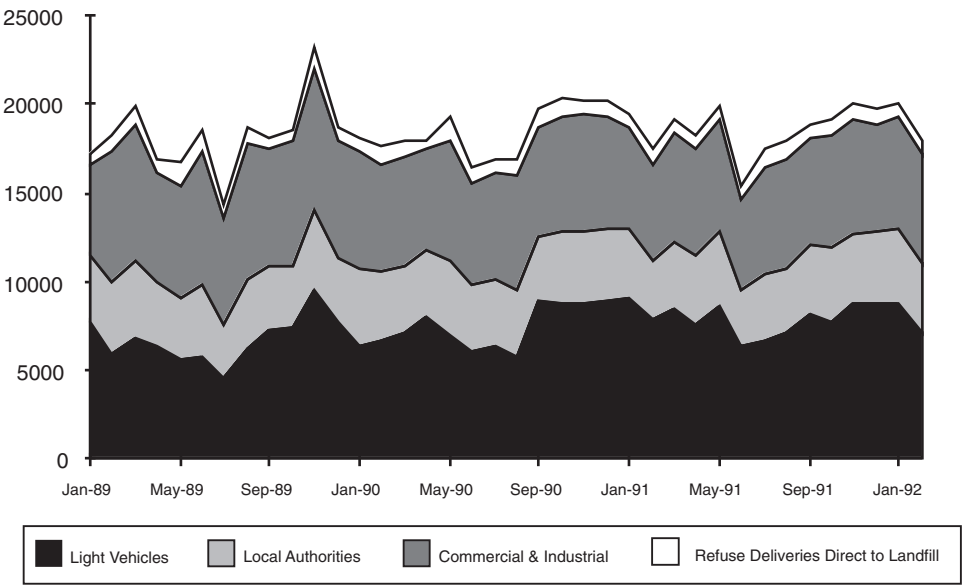


Figure 3.11: Example of seasonal variability: MSW streams in Christchurch

Sources	%	Tonnes/year
Domestic Wastes	38	259,379
Inorganic	5	37,054
Garden	4	24,703
Commerce/industry	42	284,082
Others	11	74,108
Total	100	679,326

Table 3.9: Origin of MSW streams in Auckland

### Trends up to 2005

Future trends depend on:

- changes in consumption patterns, in particular with respect to packaging;
- increases in the amounts recyclers extract from the commercial and domestic streams;
- technological progress in making the development of materials recovery facilities commercially viable;
- longer term emergence of chemicals, materials and fuels fractionation and refining plants combined with material recovery; and

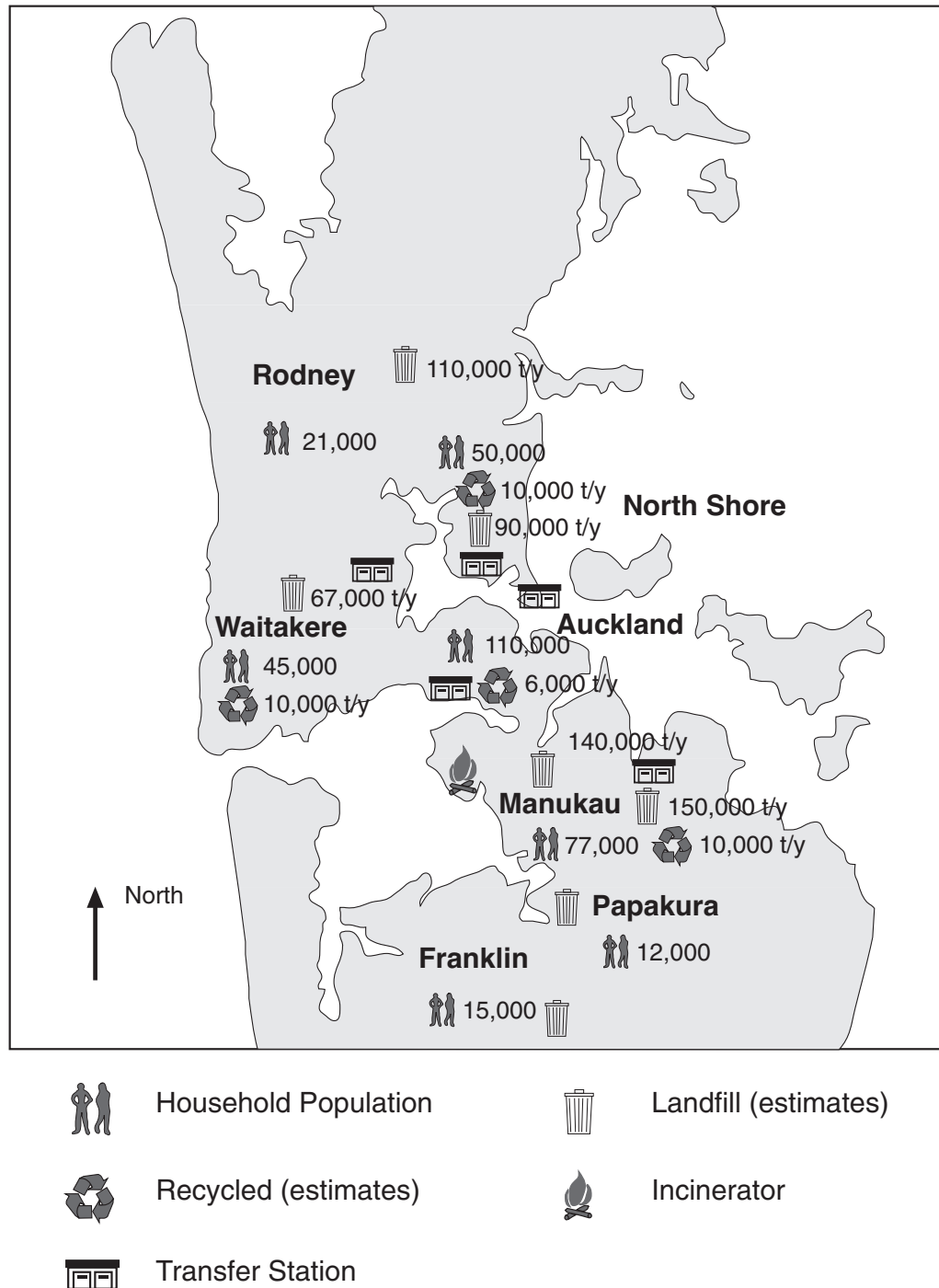


Figure 3.12: MSW in the Greater Auckland Region

- related local authority and central government policies.

Figure 3.12 outlines the MSW scene in the Auckland region where each of the seven local authorities pursue different policies. While waste management staff endeavour to co-ordinate their actions, the main components of strategies and policies are defined at the political level and are not substantially co-ordinated. As a result it is:

- extremely difficult to reach the critical mass that would be necessary for any of the technologies reviewed earlier to be implemented with favourable economies of scale. The situation is worse in other smaller urban centre, with the possible exception of Christchurch region where the main MSW stream is controlled by one authority, and is big enough to warrant exploring waste to energy facilities; and
- difficult to venture forecasts as to what changes may happen between now and 2005, as so much of the factors and stakeholders involved operate in ways far removed from economic and sustainable environmental rationality.

Scenarios would not be of much assistance at the national level as too many unspecified factors are involved. The development of robust scenarios would be only valid at the regional level and would require considerable new data collection. The range of factors to be investigated at such a regional level is illustrated in Figure 3.13.

### 3.4.4 Environmental and Social Aspects

The potential effects of the development of waste to energy conversion facilities in the urban environment by incineration and other thermal processes were described in section 4 of the Centre for Advanced Engineering's

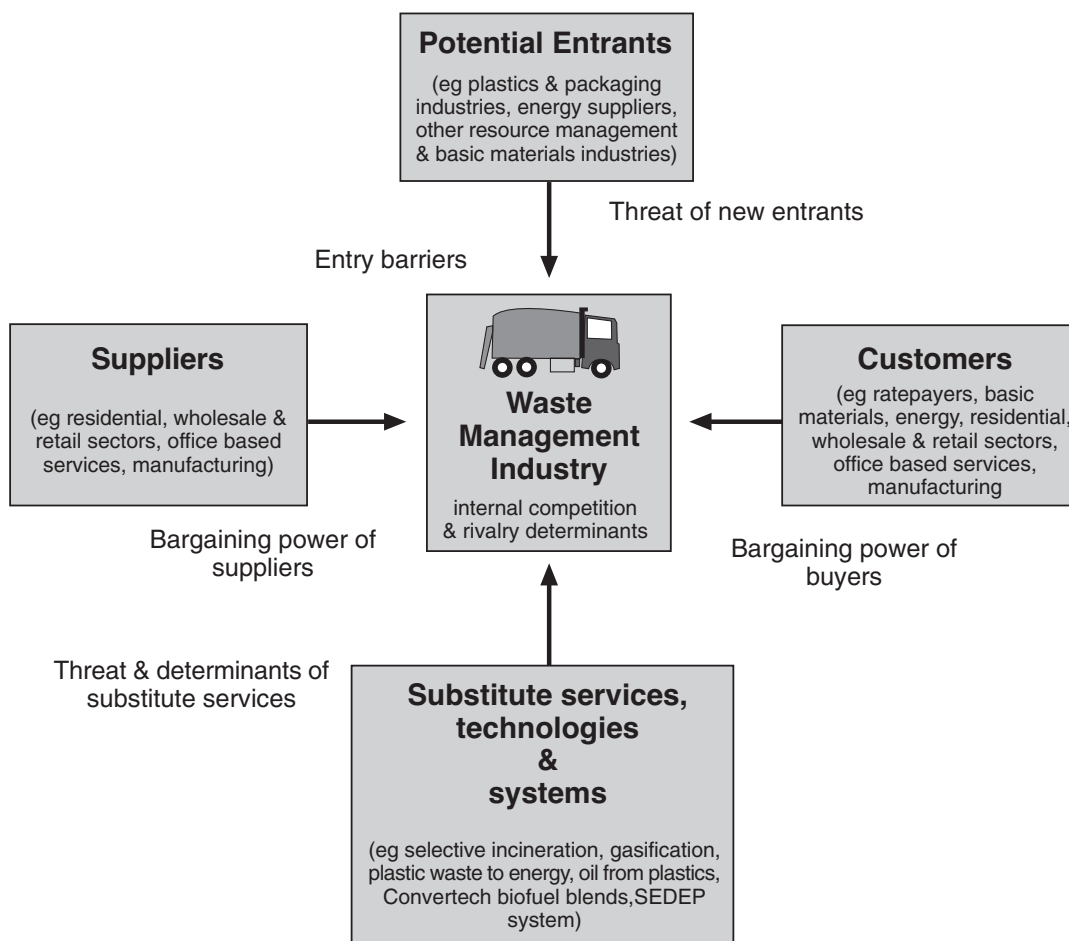


Figure 3.13: Competitive forces at play in the waste management industry

1992 publication *Our Waste: Our Responsibility* so will not be detailed here. Although energy recovery was not considered specifically, the principles relating to the thermal degradation of organic and combustible wastes are similar.

When designed and operated correctly, thermal treatment processes can have minimal environmental effects. Control of atmospheric emissions may be required for specific wastes (for example if high in chlorine). Most processes will generate solid residues which must ultimately be disposed of by other means such as landfill.

Environmental problems associated with incineration of MSW usually result from incorrect operation, assuming the system was adequately designed in the first place. The main problem areas are those associated with the products of incomplete combustion and air pollution emissions. Incomplete combustion commonly occurs due to insufficiently high temperatures being reached, and a wide range and variety of different chemical compounds result. Some of these are toxic and persist in the environment, but are usually produced in very low absolute quantities. Manufacturers of the latest incinerator designs claim to have eliminated these chemicals altogether. It should be noted that they are similar to those generated by cigarette smoking, domestic solid fuel heaters and motor vehicle engines.

Air pollution levels from incinerators can largely be controlled, but at a cost. Particulates in the form of fly ash can be easily controlled by cyclone filters, scrubbers or electrostatic precipitators. Toxic gas emissions can be controlled where necessary by wet or dry gas scrubbers or, for smaller quantities, by adjusting the waste feed rates and using fossil fuels to maintain the temperatures within the incinerator.

Generating electricity by incinerating MSW displaces emissions from conventional thermal generating plant and averts emissions which would have occurred if the waste was disposed of in landfill without gas recovery. Typically, for every kWh of electricity generated, the emissions are 1.6 kg CO<sub>2</sub>, 2.8 g SO<sub>2</sub>, 3.2 g NO<sub>x</sub>, 0.9 g CO, 0.2 g volatiles, 0.3 g particulates, 0.01 g heavy metals, and 0.7 kg solid waste.

Concerns about emissions of heavy metals and dioxins from incineration of MSW have produced strict emission regulations in Europe and the USA. This has led to the development of incinerator and gas cleaning system designs that can meet very stringent standards.

The collection and transport of large volumes of MSW to a central processing site, such as envisaged for Auckland, could create negative environmental impacts and would need to be carefully evaluated as part of a waste management system.

### **3.4.5 Economics**

Incineration can be a relatively expensive process. Costs increase significantly to allow for more stringent pollution control measures and the safe disposal of the ash. Economies of scale are evident which would inhibit development in many regions of New Zealand with relatively low and diverse population levels. British estimates for a plant processing 400,000 tonnes per year and generating 160 GWh per year of electricity were over \$200 million for investment costs giving approximately 10 c/kWh on average (8% discount rate). Against this must be offset the savings in gate fees for waste disposal by landfill and a comparison of transport distances and costs would need to be included.

Economic data as to capital costs and commercial viability within New Zealand have been provided in earlier sections. The approaches that offer the best prospects of commercial viability by 2005 are the ones pursued by Olivine and Convertech. In both cases, detailed data beyond what has been provided so far are commercially sensitive. Suffice to say that both firms are developing technology designed to be competitive within current and expected future market circumstances.

### **3.4.6 Constraints and Opportunities**

Waste to energy facilities offer very substantial opportunities. An example of potential long term development of liquid and solid waste streams for materials, chemicals, fuels and power for the Auckland Region is shown in Figure 3.14.

Similar comments as have been offered with respect to biomass crops need to be made here: very little of such potential is likely to eventuate by 2005 if development processes are left to so-called “market forces”. The key issue is that of the development of partnerships. In the present case such partnerships are probably better established at the regional level. Central government, however, would have a key catalyst role to play in facilitating such processes.

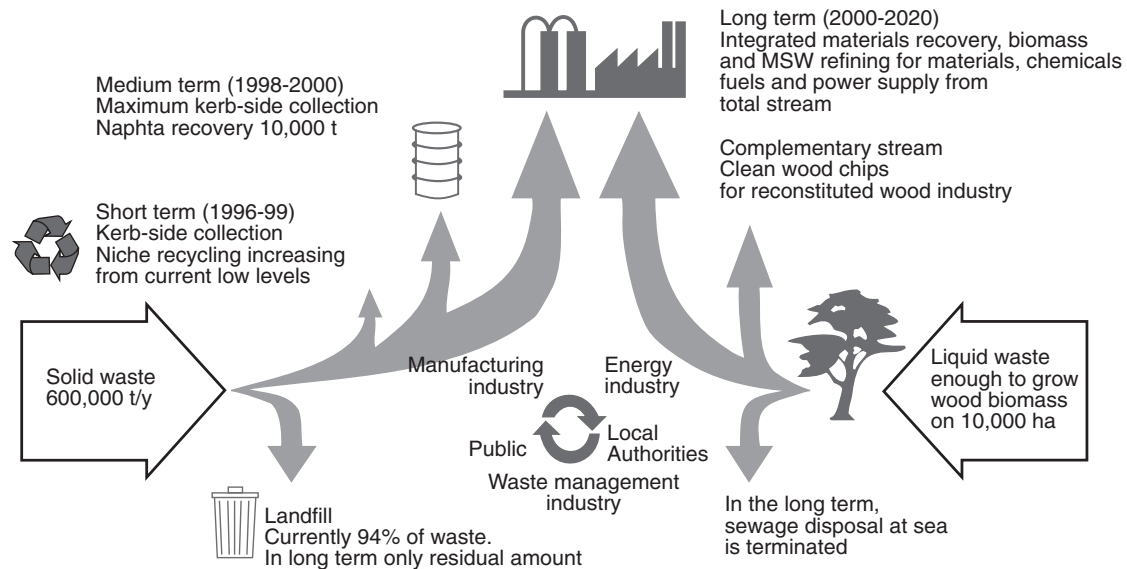


Figure 3.14: Example of long term potential development in the Auckland Region

### 3.4.7 Research Requirements

The development of substantially more detailed databases on regional MSW streams should be continued by further developing the Waste Analysis Policy requirements of the Ministry for the Environment.

The effect of recycling initiatives on the future composition of MSW should be determined. This could include analysis of landfill materials before and after a recycling scheme was instigated to determine likely changes in composition and energy content. It should be determined whether a cheap and efficient MSW incineration scheme would deter any recycling initiatives.

A review of modern incineration technologies and emissions should be undertaken based on practical experiences in Europe and the USA to determine whether the emission standards would be acceptable and achievable under New Zealand conditions. The technology is rapidly improving and any future planning and investment decisions would need to be based on recent information obtained from state-of-the-art technology.

## ***3.5 Dry Biomass Conversion Technologies***

Biomass can take many forms, but when considered as a fuel, they exhibit notable similarities. The biomass resources considered in this section are above-ground terrestrial plant components with relatively low moisture content suitable for direct burning, i.e. wood and agricultural residues. Conversion processes vary depending on the biomass form (see Figure 3.1).

The combustion of wood to provide energy as heat is a well established technology considered here in comparison with more efficient high temperature processes which are being developed for the conversion of biomass into gaseous and liquid fuels. Low temperature conversion of woody biomass to fuels by hydrolysis is also addressed.

Section 3.5.1 reviews established and emerging biomass conversion technologies and identifies some of the development issues. Section 3.5.2 addresses the situation regarding biomass conversion in New Zealand. Some of the criteria required for the effective application of biomass as an energy source are considered in Section 3.5.3.

### ***3.5.1 Technology Review***

A survey, encompassing five existing technologies for small (2 to 3 MW) cogeneration systems based on fuelwood, was conducted in Denmark on behalf of the IEA (Jakobsen and Houmoller, 1994). Newly developed technologies to replace the traditional steam turbine included steam engines, Stirling engines, indirectly fired gas turbines and pressurised downdraft combustion systems. All of these could have a future application in New Zealand.

#### ***Principles of biomass conversion***

The common objective of all biomass conversion technologies is to produce a continuous form of energy from a non-uniform feed material. The wide range of technologies for the conversion of biomass can be classified according to the principal energy carrier produced in the conversion process, which is either heat or clean gas or liquid products according to the extent to which oxygen is admitted to the conversion processes. Thus the three principal methods of conversion corresponding to these energy carriers are combustion in excess air, gasification in reduced air and thermal conversion in the absence of air.

In real applications less significant amounts of the other energy carriers may be produced in combination with the main output. For example, heat is a secondary output from biomass gasification processes and a combustible solid residue is produced by some processes. The effective integration of these outputs is important in obtaining an efficient overall energy conversion system. Once the non-uniform biomass material has been converted into a more manageable energy carrier, subsequent energy conversion processes may be necessary to produce a marketable product such as electricity, steam, fuel gas, methanol or chemical products. Therefore most biomass conversion schemes involve more than one stage; for example, gasification to provide a fuel gas which is then used in an engine for power generation. The principles of the main mechanisms of biomass conversion are considered first.

#### ***Combustion***

Combustion of biomass is the oldest conversion process and simply involves burning the biomass fuel in an excess of air to produce heat. The first stage of combustion involves the evolution of combustible vapours which burn as flames. The residual material, in the form of a carbon char is subsequently burnt with more air to give heat. Fast combustion of the residual charcoal requires a forced air supply. The efficiency of combustion depends primarily on good contact between an excess of air and the biomass.

The main products of biomass combustion are carbon dioxide and water vapour, however, tars, smoke and alkaline ash particles are also emitted. Minimisation of these emissions and accommodation of their effects are important concerns in the design of biomass combustion systems.



A range of technologies is available at scales ranging from domestic stoves through to industrial boilers such as dutch ovens, flat grates, sloping grate, pile burners/fixed bed, firetube boilers, watertube boilers, suspension burning systems and fluidised bed burners (Sims et. al., 1990).

Any dry biomass can be directly combusted, but if it has more than 0.4% alkali it can produce serious slag problems in the burner. Biomass combustion devices require special designs to counteract this, which is also the case if co-fired with fossil fuels. A major R&D evaluation is directed towards the use of gas turbines derived from jet engines to burn fuels derived from biomass.

### Gasification

The gasification of biomass is based on partial combustion in a restricted supply of air or oxygen. The basic gasification process comprises three distinct stages; devolatilisation, combustion and reduction. In the devolatilisation stage methane and higher hydrocarbons are evolved from the biomass by the action of heat, to leave a reactive char. In the combustion stage the volatiles and some of the char are partially burnt in air or oxygen to generate heat and carbon dioxide. In the reduction stage the carbon dioxide absorbs heat and reacts with the remaining char to produce carbon monoxide fuel gas. The presence of water vapour in the gasifier results in the production of hydrogen as a secondary fuel component of the fuel gas. If the hydrocarbons are subjected to high temperatures (over 600°C) then they can be broken down to carbon monoxide and hydrogen. However, if the volatile hydrocarbons leave the reaction zones without being converted, then the resulting gas contains methane and other hydrocarbon gases with oils and tars. Overall, the products are mostly gases of low to medium calorific values. Gasifiers can be designed to work at atmospheric pressure or to be pressurised and fed with oxygen instead of air to improve their efficiency.

The efficient operation of a gasifier involves a fine balance to be maintained between the feed rates of biomass and oxidant to obtain complete conversion of the char whilst avoiding excessive combustion resulting in unreacted carbon dioxide reporting in the fuel gas and thereby reducing the yield of useful gas from the gasifier. Where an inherently variable fuel like biomass is being used, this presents a significant problem of control for the gasifier designer. Gas cleaning issues are the biggest challenge. The tight control of conditions in the gasifier to achieve reliable performance makes gasifier operation significantly more demanding than the operation of a biomass combustion system.

There are two distinct types of biomass gasifier, updraft and downdraft. Figure 3.15 shows schematically these two modes of gasifier operation with the zones where each of the stages of the gasification process takes place.

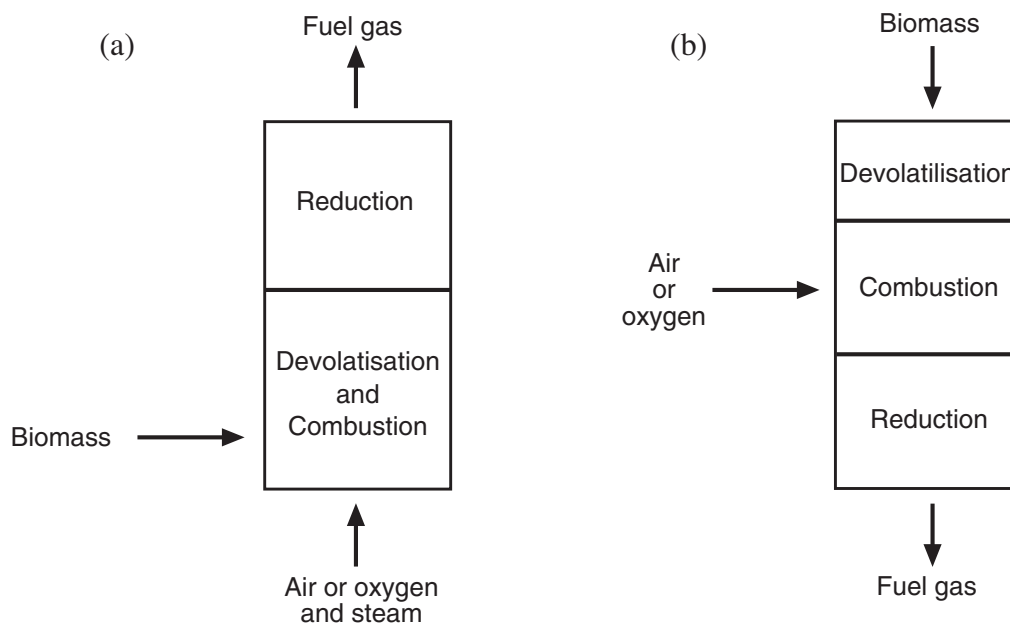


Figure 3.15: Gasifier operation (a) updraft and (b) downdraft

In an updraft gasifier the reacting biomass solids are conveyed up the gasifier as a bed of material which is typically fluidised by a rising stream of air or oxygen or steam. This mode of operation provides good mixing and therefore evens out some variability in the biomass feed material. Devolatilisation and partial combustion of the biomass occur in the lower zone of the gasifier where oxidant is available. In the upper reduction zone of the gasifier, biomass char reacts with  $\text{CO}_2$  from combustion to produce carbon monoxide fuel gas.

Because combustion and devolatilisation occur in the same zone, some of the volatile materials will escape from that zone before being broken down by the heat of combustion and will therefore be present in the gas product as oils and tars. In addition the raw gas will contain particulate material from unconsumed char and mineral matter in the raw biomass. The raw gas from updraft gasification processes is therefore inherently dusty and tarry and requires complex cleaning operations.

In downdraft gasifiers biomass is fed onto the top of a fixed bed of biomass and air is introduced into the middle of the bed. Volatiles produced at the top of the bed are drawn through the combustion zone where they are burnt. The resulting  $\text{CO}_2$  is converted to carbon monoxide fuel in the reduction zone at the base of the gasifier. As the biomass is consumed in the combustion and reduction zones it reduces in volume thereby allowing the bed to move down through the gasifier. With appropriate gasifier design the complete avoidance of tarry components in the raw gas from a downdraft gasifier can be achieved so that only dust removal is required as a gas cleaning operation.

In both of these modes of gasification the heat required to convert the biomass into gas is provided by partial combustion of some of the biomass. In some gasifier designs part of that heat is provided by a source external to the gasifier vessel. This results in a higher calorific value gas being produced.

### *Other thermal processes*

If biomass is heated in the absence of air, gases and liquids are evolved by the process of pyrolysis or destructive distillation. Heat for pyrolysis must be supplied from an external source in order to achieve this conversion of the biomass material. Where heat is the only agent in use, high temperatures are required to obtain good yields. The need for high temperature heat for pyrolysis imposes the requirement for a high quality energy source to drive the pyrolysis process. This can only be justified where the products of pyrolysis have applications with added value.

The use of pressurised steam or other chemical agents can achieve breakdown of biomass material at lower temperatures using the mechanism of hydrolysis. This enables lower quality heat to be used to drive the process. The two main mechanisms used to disrupt the woody structure are steam explosion and acid hydrolysis. In the steam explosion process, wood is heated under pressure with steam and then rapidly depressurised to release chemical compounds. In the acid hydrolysis process chemical agents are used to assist with the disruption of the woody structure.

The hydrocarbon compounds evolved from biomass by the processes of pyrolysis and hydrolysis are reactive. If products of low molecular weight are the desired output, rapid removal from the reaction zone and cooling is required in order to avoid their recombination.

### *Secondary conversion*

Biomass utilisation schemes typically involve the secondary conversion of the energy carrier produced in the primary biomass conversion process to give a useful product. For example, heat produced from combustion can be converted to steam for process use or for power generation including atmospheric, circulating fluidised bed combustors (Toft and Bridgewater, 1994). Biomass derived gaseous and liquid fuels can be used in internal combustion engines.

Clean fuel gas from biomass gasification processes can be used as a process fuel, for example in a furnace, and in situations where the advantages of a gaseous fuel over a solid fuel are sufficient to justify the complexity of biomass gasification. The more common proposed application envisaged for clean biomass-derived fuel gas is for power generation via a gas turbine or a gas engine, possibly using newly-developed pressurised circulating fluidised bed gasification (Toft and Bridgewater, 1994). Reciprocating gas engine applications suit the low calorific value gas produced by gasification of biomass in air, but a higher calorific value gas is needed for operation of a gas turbine. Table 3.10 compares applications for typical biomass gasification gases with those for natural gas.

Type of gas	Gross calorific values MJ/Nm <sup>3</sup>	Applications
Natural gas	35-40	Chemicals, gas turbines, fuel gas, gas engines
Biomass gasification with oxygen	15-20	Chemicals, gas turbines, fuel gas
Biomass gasification with air and heat	10-15	Gas turbines, fuel gas
Biomass gasification with air	3-8	Gas engines, fuel gas

**Table 3.10. Typical fuel gas applications**

If gasification is carried out in oxygen, then the gas produced has a higher calorific value because it is not diluted with nitrogen from air. The higher calorific value gas can be used as a synthesis gas for the production of methanol which provides access to the transport fuels market.

An alternative high efficiency application for gas from oxygen blown biomass gasification is fuel for a fuel cell. The commercially available phosphoric acid fuel cell is not tolerant to CO and is therefore inappropriate for biomass derived gas. The molten carbonate fuel cell, which is nearing commercial availability, can accept carbon monoxide and hydrogen and would provide a high efficiency biomass to power option. Providing clean gas to meet stringent specifications for the fuel cells will be the challenge in matching biomass with fuel cells.

### ***Biomass feedstock***

All woody biomass plant materials are comprised of cellulose, hemicellulose and lignin which comprise by weight about 43% carbon, 7% hydrogen and 50% oxygen. Accordingly, all have calorific values of about 18 to 19 MJ/kg on an oven dried basis. The moisture content of actual biomass materials can vary from under 10% to over 50% (wet basis) with corresponding wide variations in calorific values per kilogram of biomass. Biomass additionally contains small quantities of nitrogen but virtually no sulphur.

Ash contents of biomass vary between less than 1% for heart wood to more than 10% for straw and other woody agricultural residues. Typically ash contents are in the range of 2% to 3%. Biomass derived ash is high in alkaline materials which can cause severe problems due to corrosion and build up on heat transfer surfaces.

In the combustion, gasification and pyrolysis processes, the structure of biomass materials is destroyed. Thus the yields from these processes depend principally on the moisture and ash contents, and the particle size of the fuels. In the hydrolysis based processes there may also be some dependence on the biological structure of the biomass feedstock.

### ***Combustion processes***

The paper industry is the largest established user of wood wastes as fuel. In the USA over 100 million tonnes per year of wood fuel is used, mostly for steam raising. In comparison the biomass in commercial use for power generation applications is a small proportion of the total use, but at 40,000 GWh/y, exceeds New Zealand's total electricity demand. The commercial combustion technologies in the USA and Europe typically use pile burning or burning on a fixed or travelling grate in a refractory lined steam raising furnace. More recently state-of-the-art atmospheric bubbling bed combustors and circulating fluidised bed combustors have been introduced in commercial applications. Fluidised-bed combustors, which are more tolerant of variation in particle size and composition than fixed-bed combustors, provide enhanced control over emissions and attain better burnout of the biomass, resulting in a reduced amount of ash as a waste product.

### ***Conventional combustion systems***

In California there is a major commitment to biomass for power generation. There are currently about 50 operating plants in central and northern California providing in excess of 750 MWe of power. The smallest plant provides less than 3 MWe and the largest almost 50 MWe. These plants consume over 7 million dry

tonnes of fuel per year comprising sawdust, pulp processing wastes, hog fuel, in-forest thinnings, clean demolition timber, orchard and vineyard wastes and other agricultural residues.

In Denmark there is a government sponsored requirement to burn biomass, principally straw, for power generation. The Danish power generation utility ELSAM has a biomass utilisation programme with a target of consuming about 1.3 million dry tonnes per year, mostly by co-firing with coal. Straw is also commonly used in district heating plants.

One dry tonne of biomass typically generates 1 MWh of electricity at about 20% overall efficiency. This efficiency compares poorly with state-of-the-art coal fired power generation efficiencies in the range of 30% to 35%. The reasons for the lower efficiencies of power generation facilities based on biomass are mainly lower combustion temperatures and smaller scale of operation. In order to mitigate these disadvantages, co-firing of coal with biomass has been investigated at several installations in the USA and Europe. Typical biomass inputs of up to 20% of the coal feed have been shown to have acceptable impacts on the coal-fired boiler operation and efficiency (although major boiler problems have occurred, this being dependent on the type of biomass fuel used). Some beneficial effects on the formation of oxides of nitrogen ( $\text{NO}_x$ ) in the boilers have been noted. In Denmark the co-firing of straw and coal has shown that at a loading in excess of about 20% straw there are significant problems arising from the behaviour of ash particles in the flue gas path.

### *Fluidised Bed Combustion*

In parallel with developments in coal combustion, advanced designs of biomass combustors are being demonstrated or commercialised to realise higher operating efficiencies, lower emissions and lower operating costs. These include a variety of atmospheric and pressurised fluidised bed systems. Typical of these are the range of bubbling fluid bed (BFB) and circulating fluid bed (CFB) combustors marketed by the Ahlstrom Corporation.

In BFB combustors, biomass is burned in a bed of inert material, such as sand, which is fluidised by air and recycled flue gas. The amount of recycled gas is used to control the combustion and accommodate any variability in the fuel. Combustion temperatures in the region of 800°C to 900°C are used to keep  $\text{NO}_x$  emissions low.

CFB combustors use a higher fluidising velocity than BFBs, so that the burning bed material is carried out of the combustor vessel and is then separated from the flue gas by a cyclone. The recovered solids are recycled to the combustor. Developments have concentrated on achieving significant size reductions in the cyclone separation component of commercial CFB installations.

Fluidised bed technologies are commercially proven for the efficient, economic and environmentally sound combustion of a large variety of biomass fuels including wet bark and woodchips. CFBs are multi-fuel boilers with very few limitations in chemical or physical fuel characteristics. BFBs are mostly designed for specific biomass feeds when characteristics of the fuel vary between certain limits, e.g. moisture from 30 to 60%. There are about 130 Ahlstrom Pyroflow CFB boilers in operation or under construction worldwide and about 80 bubbling bed boilers; although some of these operate on fuels other than biomass.

### *Novel Combustion Systems*

An example of innovation in biomass combustion is the direct-fired 390 kW combustion turbine now in the demonstration phase in the USA and known as the PGI biowaste converter. It operates on clean pulverised wood and involves a pressurised combustor fed with air from the compressor associated with the gas turbine. After passing through a cyclone separator to remove entrained particulate matter the combustion gases enter the turbine that drives the compressor and the generator. The key to the operation of this system is the use of clean wood with a minimal ash content. A high efficiency is expected from the gas turbine system which would be enhanced by the recovery of heat from the gas turbine exhaust giving cogeneration capability.

An approach to improved combustion conditions by the use of vortex technology in an inclined grate combustor is reported from Eastern Europe. Lower  $\text{NO}_x$  emissions are noted and experience with a wide range of biomass fuels has been obtained. The innovative use of directed combustion air to enhance mixing in biomass combustors is being used in several biomass combustion developments.

## Gasification processes

### Updraft gasification

All large scale biomass gasification developments are based on updraft gasification (Figure 3.15). Table 3.11 identifies major gasification technology developments which are expected to demonstrate the feasibility of the use biomass as a primary feed for the production of fuel gas for use in power generation plant. This list is representative but is not exhaustive nor intended as an endorsement. These developments are all at the pilot plant or demonstration plant stage but none are fully commercially developed for biomass application.

Organisation	Gasifier	Technology	Status	Size MWe
Aerimpianti	Studsvik	CFB	Operational	6.7
Battelle Columbus	Battelle	MSFB	Operational	0.2
			Design	107
Bioflow	Ahlstrom	Pressure CFB	Operational	6
Elkraft/Elsam	Tampella	Fluid bed	Design	7
ENEL	Lurgi	CFB	Design	12
GEF	TPS	CFB	Design	27
PICHT	IGT	Pressure FB/O <sub>2</sub>	Operational	2-3
VUB	VUB	Fluid bed	Design	4
Yorkshire water	TPS	CFB	Design	8

CFB = Circulating Fluidised Bed; MSFB = Multi-solids fluidised bed; FB = Fluidised Bed

**Table 3.11: Biomass gasification pilot and demonstration plants**

The extensions to the basic concept of fluidised bed gasification which are included in various combinations in these technologies include circulating fluidised bed, indirect heating via recirculating sand, oxygen blown gasification and pressurised gasification. The use of CFB technology allows more tolerance of variability in biomass feeds and avoids the necessity for complete conversion of the biomass in one pass. Indirect heating of the gasifier can be achieved by using a second reactor in which unconverted biomass is burnt to provide heat to recirculating sand which is used as a heat transfer medium. This concept allows the production of a higher calorific value gas. Similarly, the use of oxygen rather than air as the oxidant allows a higher CV gas to be produced. Pressurisation of the gasification system results in a reduction in equipment size for a similar output, and avoids the need to compress the fuel gas before combustion in a gas turbine. However, pressurisation is only economically viable for the larger sizes of gasification plant because of the greatly increased complexity of plant, particularly with regard to the biomass feeding arrangements.

Although there are a large number of biomass gasification systems at an advanced stage of development, none are yet in large-scale commercial operation producing power. One of the main development issues which has not yet been fully resolved is the removal of tar and dust from the hot gas. Common approaches to gas cleaning include thermal cracking of tars in a second reactor and removal of particulates by ceramic filters. If tar removal is inadequate then deposition of tar on high temperature ceramic filters can cause a major problem.

### Downdraft gasification

The principle of downdraft gasification, as previously noted, facilitates complete incineration of tars in the gasification reaction. This can greatly simplify gas cleaning operations and leads to simple proven gasifier designs. Downdraft gasification produces a lower calorific value gas than updraft gasification but this is suitable for use in reciprocating engines. Accordingly, the downdraft gasification system is commercially available for use with engines to produce power in small scale units suited to remote locations.

An example of small scale downdraft gasification is offered by Fluidyne Gasification Ltd in a gasifier that can produce a clean gas to run a 40 kWe engine driven power generator. Similar technology has been developed in India for village power supplies in remote locations (Young and Hauserman, 1995).



### ***Other conversion processes***

There are many developments in biomass conversion which are aimed at obtaining higher value liquid products and fuel gases by the application of heat from an external source.

#### ***MTCI steam reforming***

Biomass is converted to a medium calorific value fuel gas by heating it at about 800°C in superheated steam in the absence of air. The MTCI (Manufacturing and Technology Conversion International Inc.) reactor is directly heated by burning some of the product gas in tubes in which heat transfer is enhanced by pulsing of the combustion. The process has been tested on a variety of biomass feeds and yields some char and tars as well as a fuel gas. Substantial amounts of steam and fuel gas are demanded by the process so the overall fuel production efficiency is only about 55%. Gas cleaning by scrubbing is required. The MTCI process is being developed at the pilot plant scale (Bridgewater and Evans, 1993).

#### ***Fast pyrolysis processes***

Pyrolysis is the breakdown of biomass using heat in the absence of oxygen. A wide range of biocrude oils and gases are produced depending on the operating conditions of temperature, pressure, presence of carrier gases, and residence time. In the most efficient processes, the products have a calorific range of around 8 to 10 MJ/kg.

There is a wide range of pyrolysis regimes ranging between 500°C to 1300°C and 50 to 150 bar pressure. Typical conditions to maximise yields of liquids from the fast pyrolysis process are a temperature of about 500°C and a residence time of about one second. Hence the key to successful operation is a very high rate of heat transfer. Yields of liquid can be as high as 60% of the feed material under optimum conditions, however the overall energy efficiency of the process will depend on the efficiency of the external heating system. The nature of the products obtained are strongly dependent on the nature of the feedstock and on the conditions experienced by the products before they are cooled to prevent further reaction.

Of the many pyrolysis process developments, the Ensyn process, is at an advanced stage of development in Canada with several plants constructed or planned. Fast pyrolysis is becoming more accepted as a technology with commercial potential for producing high yields of liquid fuels that can be used in many applications as direct substitutes for conventional fuels or as a source of chemicals. There are still problems to be resolved but it is clear that considerable progress is being made towards defining and solving the problems. Economic success will depend on the yield of high value products.

The latest research is in evaluating ultra-fast pyrolysis with heat rates between 1000 to 10,000 °C/s and ultra-fast ablative pyrolysis where biomass particles literally melt into oil on contact with a hot surface or other forms of heat media.

#### ***Hydrolysis***

The decomposition of biomass at lower temperatures by the use of steam explosion or acid hydrolysis has been the subject of much research. The process uses steam pressure and heat, either on its own or with the help of acids or alkalis to break down cellulose and hemicellulose into their constituent sugars. Products include C5 and C6 sugars, furfural, acetic acid, resins and pseudo-lignin. A potential advantage of this approach to biomass conversion is the recovery of liquids and chemicals in a milder way than is offered by high temperature pyrolysis, although yields of high value products will be less. Examples of these technology developments in New Zealand are the wood ethanol process and the Convertech process. The latter is being actively developed at the demonstration plant scale by Convertech Ltd in Christchurch.

#### ***Solvolytic***

Solvents are used to liquify the biomass under conditions of increased pressure and temperature. Solvents can be organic substances (such as phenols, ethylene glycol, tetralin), high pressure or supercritical water, or supercritical CO<sub>2</sub>. Products are a range of biocrude oils that need to be refined and reformed into commercial products. The solvents can be recycled.

### 3.5.2 The New Zealand Experience

#### **Commercial biomass utilisation applications**

The use of woody biomass is well established in the pulp and paper industries where boilers or furnace systems are the combustion technologies used to generate process steam, hot water, hot gases and hot air. Direct combustion of wood processing residues in 3 to 17 MW boilers or furnace systems is a common form of conversion, (Sims, 1993). Where heat is available surplus to on-site demand, cogeneration of electricity may be feasible either for use on-site or for export.

Installations ranging from 10 to 50 MWe provide adequate economies of scale. Glass (1994) identified that scale effects on installed capital and variable costs were significant below 5 MW for process heat production and below 10 to 15 MW for electricity production. Apart from such economic considerations, the scale of operation is generally determined by the availability of the resource and the required energy load.

A recent telephone survey of wood processing companies (Dare, 1996) to ascertain the levels of heat production from wood process residues, whilst not yet fully analysed, showed that a wide range of furnace types are currently used including dutch ovens, pinhole grates, Kablitz grates and suspension systems. Developments in combustion are centred on the improvement in efficiency offered by the cogeneration of power and steam.

In the forest industry, cogeneration mainly employs topping cycle systems using wood residues as fuel (Zoellner, 1991). The available wood energy input to the plant is first used to produce electricity. The exhausted heat is subsequently used for other purposes. In a bottoming cycle, the energy input is first applied as heat and the excess heat emerging from the process is then used for electricity generation through steam turbines. At present, there is approximately 200 MW of cogeneration plant installed in New Zealand (Zoellner, 1991), which is predicted to rise to over 300 MW by the year 2000 (Norris, 1996). Most of the existing forest industry cogeneration systems were installed prior to 1985, although there has been some recent investment. Four wood processing companies now have cogeneration facilities ranging from 44 kW to 21 MW with a total capacity of 47 MW. In addition, the Forestry Corporation's Waipa sawmill at Rotorua has recently installed a 3.5 MW plant. Bark and offcuts are used as fuel which, in itself, saves annual disposal costs of around \$1 million. Over 20% of the electricity generated is sold off-site during times such as weekends when the plant is not fully operational.

A large cogeneration facility is under construction at the Carter Holt Harvey pulp and paper mill at Kinleith (McLean, 1995). The plant will consist of a new wood waste boiler to produce steam and a 34 MW steam turbine generator to supply around half of the mill's electricity demand (Norris, 1996). The system will consume all the wood waste produced at the mill and could use a further 100,000 t/y of wood wastes from other nearby plants. The thermal efficiency of 80% compares well with a conventional wood-fired steam turbine power plant at around 35% (Schmidt, 1994). By comparison, a new combined cycle gas-fired power station such as that proposed at Stratford has a thermal efficiency in the order of 50%.

Sims (1993) suggested that wood-fired electricity generation could be feasible in future using forest arisings in the forest by combusting in a semi-portable plant. This could expand the potential application for forest arisings, but only if a grid or distribution network connection was feasible. Mobile plants around 5 to 15 MW scale were suggested to enable local utilities to match peak loads. This concept remains untested.

Some advanced technologies demonstrating electricity generation from biomass include gasification combined cycle, small-size plant based on internal combustion engines, and clean gas production. Commercial scale fluidised bed boilers are expected to become technically and economically feasible in the near term for both biomass combustion and co-firing with coal (Sipila, 1994).

A review of biomass combustion systems (Day, 1994) projected that emissions from these modern higher efficiency plants will come within international regulatory limits as measured by low CO values under 100 mg/Nm<sup>3</sup>, volatile organics under 20 mg/Nm<sup>3</sup>, and particulates under 200 mg/Nm<sup>3</sup>.

At present the commercial harvesting of fuel wood in New Zealand is limited to small scale operations meeting the domestic wood fuel market with typical delivered prices in the range of \$10/GJ to \$20/GJ. The cost of large scale commercial harvesting of biomass is estimated to be in the region of \$3 to \$5/GJ which, in conjunction with the low calorific value of biomass, makes it generally unattractive as a furnace or boiler fuel at present.



## ***Technologies under Development***

### ***Fluidyne gasification process***

A small-scale biomass gasifier has been in commercial production by Fluidyne Gasification Ltd of Auckland since 1984. This is a downdraft gasifier which converts wood chunks into a clean, low calorific value gas which is subsequently used to run a reciprocating gas engine to generate 40 kW of power.

The ideal feed for the Fluidyne gasifier comprises regular sized chunks of dry wood, however operation on mass-produced large wood chips has been demonstrated and is being evaluated at Massey University. The dimensions of the gasifier vessel are carefully selected to suit the fuel to be gasified to ensure efficient operation and complete consumption of tar materials. Some “tuning” of the gasifier is required to suit the particular fuel sources. The raw gas is filtered to remove fine particles so that the gas can be burnt in an engine. A small quantity of char is also produced from the base of the gasifier.

Several models of this Pacific Class Fluidyne gasifier have been supplied for use in remote locations where the labour for fuel preparation is readily available and electricity is at a premium. A larger scale design of the Fluidyne gasifier, the Megaclass with a nominal output of 500 kW of electricity, has been designed but not built. Progression from the proven Pacific Class gasifier to the Megaclass concept will involve a number of scale up and development issues, particularly with regard to ancillary equipment.

### ***Convertech biomass processing***

A novel biomass processing concept is being developed by Convertech Ltd based in Christchurch. The process involves progressive heating and pressurisation of moist flakes of biomass followed by rapid decompression, washing, further heating and pressurisation and finally superheated drying of the resulting solids. This multi-stage operation subjects biomass to a regime of temperature, pressure and moisture contents which facilitate progressive hydrolysis, and the release of potentially valuable volatile material. The bulk of the substance of the feed biomass reports as a cleaned solid product from the end of the process, however a yield of about 10% to 15% of volatile material is also expected.

The economic viability of the process depends strongly on the yields of high value materials obtained from what is essentially a wood-refining process. One potential high value product from the process is the chemical furfural which may be recovered from the volatile material. The solid residue from the end of the process could be used as a clean demineralised solid fuel or might attract a higher value as a raw material for a new construction material. Removal of the alkali component from the biomass could help solve slag build-up problems which often result from biomass combustion, when the fuel has a high silica content.

A process development demonstration unit is under construction in Christchurch. The complete Convertech process design comprises five interconnected recirculating steam loops. The demonstration plant will consist of one loop which can be used to reproduce conditions in any of the five loops. It is expected that this plant will be used to obtain yield data to facilitate prediction of the overall performance of a complete plant.

### ***Wood ethanol process***

A development of the established acid hydrolysis process is proposed by Wood Ethanol Ltd. of Rotorua, incorporating novel processing steps (Just, 1996). The principal products are a saleable ethanol product derived from fermentation and a methane fuel gas product which is mostly used to drive the process. The economics of the proposed process depend on a high value for the ethanol product and a free or negatively priced feed material. The NZFRI also investigated a wood to ethanol hydrolysis process in the 1980s. A pilot scale plant was built to demonstrate the Madison dilute sulphuric acid process. The technology proved successful and resulted in a new process for the production of methanol from the anaerobic digestion of the hydrolysis stillage (Burton et. al., 1984).

### ***Other biomass conversion research***

In the 1980s a great deal of biomass conversion research was carried out in New Zealand with funding from the Liquid Fuel Trust Board and the New Zealand Energy Research and Development Committee. Since that time there has been further research into sources of biomass derived fuels for both spark ignition and diesel

engines, but largely based on non-woody biomass sources. These include production of biodiesel from vegetable oils and animal fats, and alcohol fuels from a range of energy crops such as fodder beet.

Current research objectives include bark utilisation and other waste material utilisation programmes using private sector and national funding. The utilisation of wood ash as a soil conditioner is also being evaluated.

### **3.5.3 Environmental Aspects**

A major driving force towards the use of biomass as an energy source is concern about Climate Change and the need to reduce emissions of fossil fuel derived CO<sub>2</sub>. New Zealand has made a commitment to stabilise net CO<sub>2</sub> emissions at 1990 levels by the year 2000 during which period economic activity is expected to grow by about 20%. Attainment of this target is intended to be achieved by reforestation of pastoral land and improvements in the efficiency of energy use.

Beyond 2000, further reductions in fossil fuel CO<sub>2</sub> emissions per unit of production will be progressively more difficult to achieve, therefore substitution of fossil fuel energy sources by bioenergy will be needed. Biomass is a CO<sub>2</sub> neutral fuel because the CO<sub>2</sub> released to the atmosphere by its combustion is equal to the CO<sub>2</sub> which was absorbed when the tree or plant was growing. Therefore replacement of fossil fuel energy by biomass-derived energy will contribute to CO<sub>2</sub> emission control.

Other constraints relating to environmental emissions will need to be met by biomass utilisation schemes. In comparison with coal, biomass presents less environmental control problems because it contains little if any sulphur and the lower combustion temperatures lead to reduced NO<sub>x</sub> emissions. However, the higher tonnage of biomass which would need to be transported to meet the same duty as a coal application could give rise to environmental concerns.

For a low-efficiency combustion plant fuelled by wood residues and driving a steam turbine, typical atmospheric emissions per kWh of electricity generated are 1.9 kg CO<sub>2</sub>, 1.9 g SO<sub>2</sub>, 1.0 g NO<sub>x</sub>, 5.1 g CO, 0.2 g volatiles, 1.0 g particulates, zero heavy metals, and 15 g solid ash waste which is rich in P and K and suitable to recycle to the land. Gasification plants will give far lower emissions per kWh of electricity.

### **3.5.4 Economics**

#### **Process heat**

The economic viability of biomass fuelled process heat schemes is primarily dependent on the cost of the biomass fuel resource. For harvested wood chips delivered to a central combustion facility, costs, could be as low as \$3/GJ, but costs closer to \$5/GJ might be more reasonably expected. Where waste material from a wood processing operation is the fuel source the fuel is essentially free and its effective disposal might even produce an income of up to \$1/GJ (as opposed to a fuel cost). The dependence of the costs of biomass fuel resources on sources, harvesting methods and transport distances were discussed in section 3.2.

The other major costs of a process heating system are the capital charges and operation and maintenance costs. A capital cost in the region of \$200/kW thermal output may be expected for a commercial biomass fuelled boiler with operation and maintenance costs in the region of \$40/kW year. On the basis of a load factor of 80%, a rate of return of 10% and a plant life of 20 years, these figures translate into a cost of about \$9/MWh or \$2.5/GJ of energy delivered. Fuel costs are not included. Where the fuel source is wood waste the economics are attractive. However, the cost of harvested biomass fuel adjusted for the effect of efficiency of combustion can add from \$3.5/GJ to \$6.5/GJ to the cost of the delivered heat, making the use of harvested wood an unattractive option for the production of process heat in most situations.

#### **Power generation**

Capital cost estimates for biomass fuelled power generation plants are very variable, particularly for technologies which are under development. Examples of power plant capital costs quoted in the proceedings of the 1995 Biomass Conference of the Americas vary by a factor of two or more for the same technologies. Some of the wide variation between cost estimates is due to differences between basic equipment costs and

total project costs. However, there are also strong dependencies of capital costs on development status and plant size. Table 3.12 is based on estimates made by Toft and Bridgewater (1996) using the Bioenergy Assessment Model (BEAM) (Ford-Robertson, 1996) which incorporates several other models of biomass economics. The capital cost estimates shown in Table 3.12 are taken to represent total investment in a new plant installation.

Technology	Generating efficiency %	Capital cost \$NZ/kWe	Power cost with fuel at \$3/GJ c/kWh	Power cost with fuel at \$5/GJ c/kWh
CFB combustion with steam cycle	23.5	4600	12.5	15.6
Atmos. pressure fluid bed gasifier with dual fuel engine.	27.5	4400	12.2	14.8
Pressurised gasifier with combined cycle gas turbine	38	5500	12.6	14.5

Basis: Projected commercial operation; Plant size 5-100 MWe; Load factor = 80%; Operation and maintenance cost = \$40/kW.y; Rate of return = 10%; Plant life = 20 years

**Table 3.12: Examples of cost estimates for biomass power plants**

The figures presented in Table 3.12 indicate that there is a small economic benefit to be obtained from improved efficiency of the power generation system when the cost of the biofuel resource is high, but that at low biofuel costs there may be no advantage to be gained from improvement in conversion efficiency if the associated increase in capital cost is high.

The electricity generation costs projected do not compare favourably with present day power generation costs in New Zealand (other than the Clyde dam perhaps). However they may be improved by lower cost biomass collection systems and further improvements in conversion technologies.

A factor which would impact significantly on the comparative costs of power generation from biomass and fossil fuels would be the introduction of a fossil fuel carbon tax. For example, a tax of \$10/tonne of carbon applied to fossil fuels would be equivalent to a subsidy of \$1/GJ on the cost of biomass fuel not subject to the tax.

### ***Chemicals and liquid fuels production***

The production of added-value materials, such as chemicals from dry biomass, may result in economically viable conversion processes, particularly if integrated with power production systems. The economic viability of such options will depend on the yields obtained, the costs of purification and the market values of the materials obtained, including any by-products.

The production of methanol from biomass derived gas produced in an oxygen-blown or indirectly heated gasifier could provide a route to the transport fuel market. Flexible fuelled vehicles which can run on an 85%/15% blend of methanol and gasoline are commercially available in the USA. The potential yield of methanol from wood via the gasification/synthesis route is about 50% on an energy basis. US studies have shown that the cost of producing methanol via this route is about 1.5 to 2 times more expensive per GJ than gasoline at present.

## ***3.5.5 Constraints and Opportunities***

Currently, all biomass powered electricity generation facilities in commercial operation employ direct-fired combustion units to produce steam for power production. This technology is appropriate where the biomass source is available at no, or low, cost. For the use of more expensive biomass sources which require gathering and transport, more efficient processes based on gasification and the use of combined cycles are preferred.

There are economies of scale to be obtained in biomass conversion processes. In particular, for gasification plants in excess of about 50 MW capacity pressurisation of the gasification vessel becomes economically attractive. However, the cost of supply of biomass to a central processing station increases with capacity, because the biomass has to be transported over greater distances. For this reason a limit of about 100 MWe for a biomass fired power plant is typically recommended.

The cost of power generation from harvested biomass does not compare favourably with power generation from fossil fuels in large power plants at present. Whilst the cost difference may change over the next decade due to reduction in biomass collection costs, improvement in biomass conversion technologies and environmental concerns which may be manifest as a carbon tax, it is unlikely that biomass power generation will be able to compete directly with large scale fossil fuel power plants until there is a substantial increase in fossil fuel prices.

The introduction of biomass fuelled power generation plant is most likely to occur first in locations where fossil fuels and electricity transmission are expensive, biomass is readily available, the rural infrastructure suits biomass gathering and the power demands match the small size of biomass power generation plants.

Such conditions tend to occur in developing countries and in remote locations. The introduction of complex plant in such locations can be difficult because of the need for support in terms of training and maintenance. Training of operators in the use of biomass processing equipment is of particular importance to ensure continued trouble free operation.

### **3.5.6 Further Research Requirements**

The successful introduction of woody biomass conversion technologies depends not only on a sound economic base for the operation but also on ensuring operability of the system. The main areas of research into woody biomass conversion technologies are:

- development of knowledge of available indigenous biomass resources and their suitability for different conversion processes;
- development of a good understanding of the biomass preparation requirements of the processes;
- development of conversion processes, in particular addressing reliability and ease of use issues;
- in using updraft biomass gasification for the production of a gas turbine fuel, a prime concern is gas cleaning and it is in this area of the technology that most development work is continuing; and
- in using downdraft gasification processes the main need is for scaling up of proven processes to an economically viable scale of operation.

Advanced biomass energy systems under development are showing significant improvements in system performance are possible, including reduced emissions and higher system efficiencies. Next generation technologies to be developed include:

- advanced steam cycle systems;
- integrated gasification/advanced turbine systems with high efficiency gas clean up systems;
- biocrude-fired combustion turbine and diesel systems with pyrolysis technology refinements; and
- fuel cell systems with assessment of fuel cell technology that can utilise biomass derived gases (Hardesty, 1994).

### **3.5.7 Conclusions**

Systems for the combustion of woody biomass waste to provide process heat and steam for power generation are well established. A large number of biomass gasification processes are under development worldwide, but none of the large-scale processes are yet commercially established. A number of processes for the

production of chemical and liquid fuels are being developed to produce added-value materials. Where biomass is available as a collected material at no cost, biomass conversion processes can be economically viable. Where the cost of collection and transport of biomass has to be met by the conversion process, the economics of the production of heat, fuel gas or electric power are poor.

The introduction of a fossil fuel carbon tax, or similar economic instrument to reduce CO<sub>2</sub> emissions would make a significant improvement in the economics of biomass conversion.

The scale of operation of biomass fuelled power plants is limited to about 100 MWe. Co-firing of coal and biomass in power generation plant has been shown to be viable in installations in the USA and Europe at coal to biomass ratios in the region of about 4:1. This approach to biomass utilisation may become applicable in New Zealand in the future if coal-fired power generation needs to be extended.

Biomass conversion technologies are most likely to be introduced first in relatively remote locations where the local economic constraints are well suited to the technology, where fossil fuel reserves are limited and renewable biomass reserves are plentiful.



## 3.6 Conversion of Wet Biomass

A number of processes exist to convert biomass with a high initial moisture content into liquid and gaseous fuels. This section will briefly outline fermentation and anaerobic digestion technologies and their potential, and outline the feasibility of producing “biodiesel” from vegetable oils and animal fats.

### 3.6.1 Technology review

Some forms of biomass are made up largely of sugars and other chemicals that can be fermented into a range of products. To maximise yields, pre-treatments are required to breakdown the cellulose and hemicellulose into their constituent sugars prior to their fermentation. These pre-treatments can be by hydrolysis or enzymatic techniques, the latter being more expensive until recently and therefore used mainly for high added-value products other than energy.

#### **Ethanol**

Fermentation is the most developed technology to produce ethanol and major improvements in the process have been achieved in recent years. Basically it is an anaerobic biological process whereby sugars are converted to alcohol by the action of micro-organisms, usually yeast. Processing of whole plants, such that ligno-cellulosic materials can be utilised as well as the sugar and starch fractions of the seeds or tubers, will lead to greater competitiveness with fossil fuels in the future. Ethanol as a transport fuel, either pure or blended with petrol or diesel, would require substantial modifications to downstream technology and infrastructure including fuel distribution, refuelling facilities and even engine conversions depending on blend levels.

In the USA 5% of the annual corn maize crop is used to produce 4 billion litres of ethanol (Graham, 1996). A \$US0.14/l tax credit is provided as a national subsidy on the fuel used in gasoline blends without which it would not be economic. Research advances in the simultaneous saccharification process, whereby enzymes convert pentoses to ethanol, could lead to a significantly cheaper overall process, thereby reducing the gap between corn alcohol and petrol. The liquid resulting from fermentation contains only 10% alcohol which must be distilled off. This involves high heat inputs and disposal of the stillage. Final product ethanol (100%) has an energy content around 30MJ/kg or 24 MJ/l. Blends of up to 20% ethanol can be run directly in many existing models of spark ignition engines but diesel engines need modifications.

Other fermentation processes are also being evaluated in Europe where for example, electricity and oil industry companies have invested in the Kolbe-Kaplan approach. This is based on the anaerobic fermentation of sugars to produce fatty acids which then undergo electrolysis to produce a range of alkanes from C6 to high alkanes in the C15 to C22 range. Complementary technologies are being developed or improved as part of the development of the biomass industry. These include distillation and other separation techniques to produce fractionates, alcohols and biocrudes as well as various catalytic and reforming techniques derived from the petroleum and chemical industries to upgrade intermediary products into a wide range of fuels and chemicals.

#### **Methanol**

Gasification of biomass using oxygen to replace air produces a gas of  $H_2$ , CO and  $CO_2$ . If  $CO_2$  is removed, synthesis gas remains from which almost any hydrocarbon compound can be formulated. Methanol is one such product with an energy value of 23 MJ/kg. Its synthesis requires a series of complex chemical processes using high temperatures and pressures. The liquid fuel produced can be used for a range of purposes including synthetic petrol using the Mobil process as exemplified by the Motunui methanol plant in Taranaki where methanol is produced from natural gas. Conversion of existing designs of internal combustion engines would be needed to run on high methanol concentrations. Specialist methanol engines have been developed.

#### **Biogas**

The process of anaerobic digestion occurs in the absence of air whereby mesophilic anaerobic bacteria decompose organic matter converting it into methane and carbon dioxide. The process occurs naturally on the bottom of ponds and wetlands. Biogas is commonly produced from sewage concentrations, animal



manures, food processing residues and green crops. The gas is a mixture of  $\text{CH}_4$ ,  $\text{CO}_2$  and impurities such as hydrogen sulphide, the proportions depending on the feedstock material, the scale of the plant, the retention time in the digester and the process temperature, around  $35^\circ\text{C}$  being preferred. The hydraulic retention time must be short if the process is to be economic and good progress has occurred in this regard in the last twenty years (Campbell and Cohen, 1996).

Methane gas has an energy content of  $38 \text{ MJ/m}^3$  at normal pressure whilst  $\text{CO}_2$  has no effective energy content and should be removed before compressing into storage tanks in order to conserve space.

The feedstock is added as a slurry to the digester of which there are many designs. Here the bacteria break down the organic matter into sugars and then into several acids which are decomposed to produce the final gas. This leaves an inert residue which can be used as a soil conditioner/fertiliser. Digester sizes range from  $1$  to  $2000 \text{ m}^3$  and the digestion process, whether batch or continuous, usually lasts for 1–4 weeks until complete. The bacterial action generates some heat but additional heating is often required using some of the biogas to maintain the optimum temperature. For each dry tonne of feedstock, 200 to  $400 \text{ m}^3$  of biogas methane can be produced containing around 8–16 GJ of useful energy.

Ideally the feedstock should not be over diluted with process water to achieve high quality gas production. A new computer assisted Valorga process with 45% solids in the slurry has achieved high conversion efficiencies (see section 3.4.1).

### **Landfill gas**

A large proportion of MSW is biological material as outlined in section 3.4. Once disposed of in landfills, conditions suitable for anaerobic digestion result. The methane produced can be hazardous as it is explosive. Only since the 1970's has the concept been developed to capture this gas and utilise it to produce heat and power.

The process is slow due to lower temperatures and drier conditions than in a digester but the  $\text{CH}_4/\text{CO}_2$  product is the same. In theory yields of  $150\text{--}200 \text{ m}^3$  of gas per tonne of wastes collected should be achievable, the gas having a heat value of 5–6 MJ/kg. In practice over the life-time of the site, the yields are a lot less than this. The gas is collected by an array of buried perforated pipes and drilled wells. It can be burnt direct for heating purposes or used to run gas engines driving electricity alternators.

In the long term, as the use of landfill sites is superseded by recycling and more efficient energy recovery systems from MSW, landfill gas will decline as a resource.

### **Biodiesel**

Triglycerides from natural plant oils and animal fats can be simply converted into esters which can be substituted for diesel fuel or blended with it. This was realised by Rudolf Diesel when he first developed the compression ignition engine in 1907 so it is not a new concept. Renewed research work in the 1970's/1980's carried out world-wide on modern diesel engines showed a range of oil crops would make suitable fuels and that their esters were excellent diesel substitutes having high cetane values. Rapeseed oil esters are now commercially available in several European countries and research activities in North America are expanding.

Existing diesel engines run satisfactorily on selected esters and blends without any need for modifications. Raw vegetable oils will also work in the short term but can lead to later problems occurring due to the high viscosity in particular. Specialist engines were designed by the Elsbett company in Germany to run on unprocessed vegetable oil which has a higher viscosity than either diesel or esters. Some problems of storage and emissions are yet to be resolved. Emissions from esters are satisfactory and, in terms of  $\text{CO}_2$  and particulates, better than diesel fuel combustion. Storage and handling of esters does not appear to be a problem as long as the residual alcohol has been largely removed.

## **3.6.2 New Zealand Experience**

### **Ethanol**

In the 1970's the production of ethanol was evaluated from a range of crops including fodder beet. A series

of New Zealand Energy Research and Development Committee reports resulted. Around the same period the NZFRI was investigating the ethanol from wood route (section 3.5.2). Although pilot plants were built no commercial activity resulted due to the drop in the crude oil price.

Ethanol from dairy feedstocks is a mature technology. Three plants exist representing both batch and continuous fermentation technology (Robertson, 1996). The ethanol is used as a solvent or as a beverage additive. As an energy source, ethanol via dairy products would be a very efficient route for harnessing solar energy. Other than using the limited volumes of the waste product whey, it would not be a practical proposition to produce dairy products as an energy source.

### ***Methanol***

Competition with relatively cheap methanol production from natural gas has eliminated any demand for researching methanol from biomass. This may change as natural gas reserves are depleted in the future.

### ***Biogas***

Sewage treatment plants have been methane generators for decades, the gas being used on site to produce power for local consumption. The Christchurch plant is a good example. A 1.55 MW gas generator was recently installed which will provide power for the plant, the nearby pump station and for sale to Southpower. Two existing generators will enable a total of 2.9 MW to be produced at peak times. A five year payback period is expected from the savings in electricity charges and sale of surplus power.

Considerable biogas research was undertaken at the Ministry of Agriculture's Invermay Research station in the 1970's/1980's using animal wastes and green crops as feedstock. Several on-farm biogas plants were built and operated successfully but, at this small scale, considerable dedication was required to meet the high labour demand. Use of the gas for power generation or as a vehicle fuel was well understood. The New Zealand Standards Association (1987) produced a code of practice which remains a useful set of guidelines.

Most small farm scale plants have since closed down, though there has been a recent revival in interest at the medium scale following the problems of waste disposal under the Resource Management Act. For example a pig farmer in the Wairarapa recently installed a plant whereby the waste from 6000 animals is separated into solid and liquid streams and each treated differently to increase the gas yield (Figure 3.16).

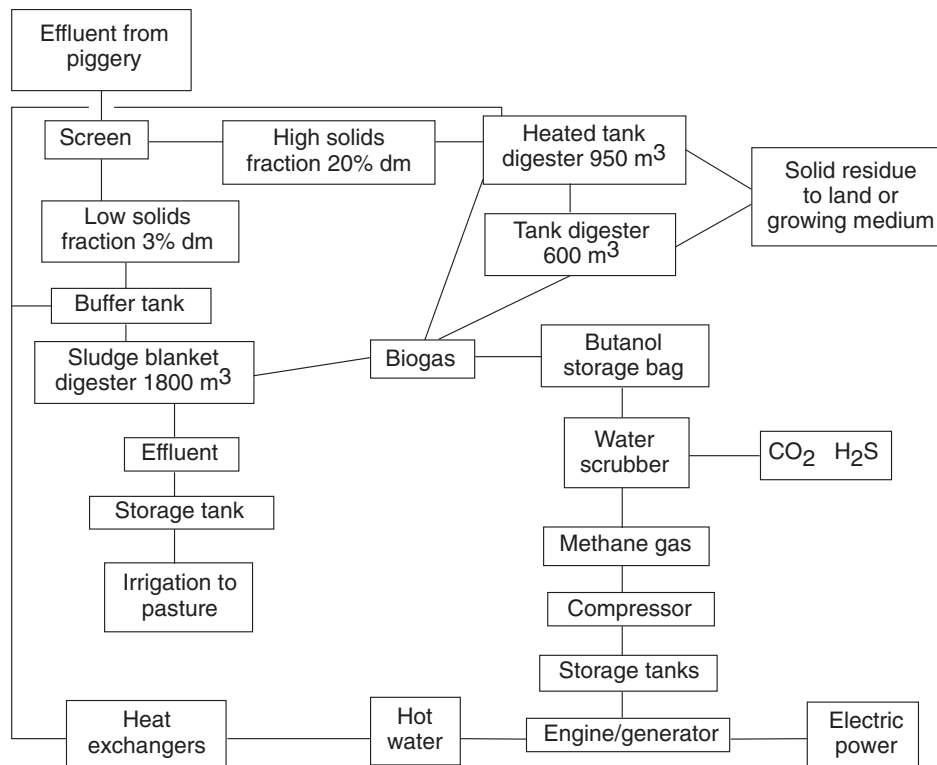
The higher solid component enters the first of two tank digesters heated to 35° C. After a two week residence time it is transferred to a second smaller tank. The residue is applied to nearby pasture land. The low solid effluent stream goes into a UASB (sludge blanket digester and after a residence time of only a few days, is pumped to an irrigation scheme covering 340 ha of dairy farm pasture. In a true energy system the irrigation could go on to green crops which in turn could be used to supply more feedstock for the plant. The gas produced is used to generate around half the power demand of the farm via a 190 kVA generator powered by a Caterpillar gas engine. The waste heat is used to heat the tank digester and any surplus to warm the low solid effluent stream. The economics appear dubious if based purely on energy savings so the operation is better considered as a means of partly offsetting the costs of waste disposal which is more stringently regulated under the Resource Management Act.

On a larger scale several food processing plants, such as Cedenco Ltd in Gisborne, have installed an anaerobic digester to deal with the waste product. At this scale, as for city sewage plants, it is feasible to employ specialists to operate and maintain the plant. Recent developments and experience in treating a wide range of waste products including MSW, toxic wastes, high protein wastes, high lipids wastes, and cellulosic wastes, have led to reductions in plant capital and operating costs.

### ***Landfill gas***

Several sites are producing gas in Auckland (2), Hutt Valley, Porirua and Green Island, Dunedin. Gas collection efficiencies are in the range of 50% to 60%, and the conversion efficiency of the gas engines gives an overall efficiency around 18% (van der Voorn, 1996). Future sites could use membrane collection systems to increase the collection efficiency to 90% and cogeneration systems of 80% to give an overall output efficiency of 72% if a use for the heat can be found nearby.

The purification level for the gas depends on its utilisation. At Green Island it is scrubbed (washed with water



**Figure 3.16: Anaerobic digestion plant outline of Wairarapa pig farm**

under pressure to remove  $\text{CO}_2$ ) and the 97%  $\text{CH}_4$  is then blended with air to give the optimum gas blend for pipeline reticulation.

Management of a site to maximise gas yield is only possible when starting a new landfill site rather than if drilling into established landfills. Recycling of the leachate effluent is important to maximise gas output and avoid groundwater pollution.

### ***Biodiesel***

An extensive research and demonstration programme funded largely by the Liquid Fuels Trust Board and concentrating on tallow esters and rapeseed oil, was completed successfully in 1987. It included fleet trials of a wide range of vehicles operating on a 10% blend of esters with diesel and is detailed in Sims (1996a).

## **3.6.3 Energy resource and potential**

### ***Ethanol***

Carbohydrate crop production could be widely established if a real demand for ethanol fuel was realised. In addition wood ethanol could become available, though the feedstock resource would compete with other uses such as wood products or fuel for combustion, power generation, or cogeneration. The limitation is land availability which is dependent on competition from other farm enterprises and their opportunity costs (Sims, 1996b). Currently pastoral farming is in decline due to a downturn in commodity prices for meat and wool but this may not remain the case. Medium term contracts will need to be negotiated with growers before an ethanol plant can be constructed in a particular region. Approximately 150–200 l of ethanol can be produced per hectare but the energy inputs to grow, harvest and process the crop are high, giving an unacceptable energy ratio.

### ***Methanol***

The biomass feedstock resource is again limited by land availability in competition with food and fibre crops.

## Biogas

It is difficult to accurately predict the feedstock resource due to the choices available for disposal of waste or conversion to useful products other than energy. Straw for instance can be combusted, baled and sold for compost, ploughed in, or used as animal feed. Table 3.13 provides a summary of biogas potential assuming solid wastes are a potential energy source rather than a waste disposal problem.

Waste resource	Annual volume (tonnes)	Methane potential ( $\text{m}^3 \times 10^6/\text{y}$ )	Gross energy potential (TJ/y)	Electrical energy potential (GWh/y)	Diesel <sup>3</sup> substitution potential ( $\text{l} \times 10^6/\text{y}$ )
Refuse	2,000,000	220	8140	678	178
Cereal Straw <sup>1</sup>	400,000	100	3700	308	81
Newspaper	300,000	41	1520	126	33
Vegetable/meat processing <sup>2</sup>	650,000	260	9620	800	210
Piggery manure	27,000	8	300	25	6
Poultry manure	100,000	76	2820	235	61

Notes: 1 Maize stover @ 9 x 106 tonnes dry matter (tdm)/y not included

2 Biodegradability assumed to be 80%

3 Gross diesel yield equivalent excluding energy inputs for gas scrubbing and compression

**Table 3.13: Biogas energy potential from New Zealand wastes**

In addition growing green energy crops for biogas feedstock would add to the resource but would be limited by land availability. Field trials at the Invermay Agricultural Research Station in the 1970's showed that sustainable crop yields of 12 to 21 tonnes dry matter (tdm)/ha/y were achievable, the digested residue being returned to the field to recycle the nutrients. A crop yield of 16 tdm/ha/y would provide 180 GJ/ha/y of biogas.

## Landfill gas

Current New Zealand landfills have been estimated to generate over  $240 \times 10^6 \text{ m}^3$  of gas each year, 55% of which is methane. This assumes one tonne of typical MSW containing 50% biodegradable organic matter at 50% moisture content (see introduction to section 3.4) will produce a total volume of  $220 \text{ m}^3$  of gas (Stewart, 1996).

The potential total gas volume of 4 PJ/year is mostly difficult to recover as many landfills are too small to warrant landfill gas extraction. The gas volumes are also reduced on poorly designed sites where leachate loss occurs. Where feasible, collection of landfill gas should be encouraged and conversion to heat and power undertaken as the resulting conversion of  $\text{CH}_4$  to  $\text{CO}_2$  will lower the climate change impact.

## Biodiesel

Tallow production by the New Zealand meat industry is around 100,000 t/y. After conversion to esters this equates to approximately 10% of the national transport diesel demand. In addition oilseed rape crops can be grown at yields up to 3 t seed/ha but typically 1.8 t/ha on average. At an extractable seed oil content of 40%, approximately 1.4 million ha of rapeseed oil would be needed to displace the remaining 90% of diesel. This is a similar land area to that currently planted in exotic forest.

### 3.6.4 Environmental and social aspects

Production of liquid and gaseous fuels from "wet" forms of biomass would provide the benefits of carbon cycling and employment opportunities. In addition where waste products can be utilised, their disposal problems can be resolved in accordance with the Resource Management Act. The value of the energy products and services produced would offset the disposal costs.

### 3.6.5 Economics

#### **Ethanol, methanol and biodiesel**

Growing energy crops is costly even where high yields can be achieved and low input production methods are used. The crops must be grown in a sustainable manner and the total energy input into the process should be substantially lower than the energy contained in the final fuel product. Energy ratios are in the order of 1:2 for ethanol and 1:6 for rapeseed oil esters. The cost per GJ of final product is over double that of current retail petroleum fuel prices. This includes the value of any co-products such as high protein meal and glycerol from oilseed rape esters.

Tallow esters utilise low grade tallow from the meatworks which has an export value of around \$100/t. Following an extensive research programme on tallow esters in the 1980's, the Liquid Fuels Trust Board concluded the crude oil price would need to reach \$US27/barrel (1987 \$) for tallow esters to become economic (Sims, 1996b).

#### **Biogas**

Life cycle cost analyses in the biogas section of the 1993 Ministry of Commerce Renewables report (authored by Campbell, J.) can be summarised as follows

Waste feedstock	\$0	
Green crop feedstock	\$5/GJ	
Transport	\$1/GJ	
Capital cost of digesters, plant etc	\$2500/kW for crops	\$1000/kW for wastes
O & M	High for crops	Low for wastes
Total electricity generation costs	11-18c/kWh	2-5 c/kWh

#### **Landfill gas**

Economic analyses vary markedly with the site, scale, local gas market etc. Existing sites appear to be viable but detailed costings are in commercial confidence and so cannot be reported here.

Competition is often with the local natural gas supplier. In the Wellington region for example about 6% of the market is supplied by landfill gas. However the customers also need the security of connection to a natural gas supply to overcome the risk perception of this new and, to them, unproven energy source. The economic benefit to gas users in the Wellington region from the introduction of competition for gas supplies was estimated to be around \$3M/annum (van der Voorn, 1996). This includes customers who have negotiated a better price for their existing gas supplies by threatening to change over to landfill gas but then receive a better deal from the local gas company.

### 3.6.6 Constraints and opportunities

#### **Ethanol**

The main constraints are land availability; low crop yields; low energy density compared with petrol and diesel; production costs; and stillage disposal.

The opportunity may occur in the future for ethanol to be used in New Zealand as a petrol additive, ethanol being a useful octane enhancer, and an oxygenate to reduce CO outputs.

#### **Methanol**

Competition from methanol production from cheap natural gas is a major disincentive.

**Biogas**

Lack of adoption of the technology in many waste streams is due to poor comprehension; risk of the biological process failing; transport of feedstock being too expensive; multiple end use decision options for a finite resource; and inconvenience. Campbell and Cohen (1996) list more detailed barriers.

The major opportunities relate to the enforcement of environmental laws and to the research and development needed to enhance gas yields from, for example, digestion of the lignin component of the plant.

**Landfill gas**

Customer uncertainty in the technology has been a constraint but this should become less of an issue now existing installations are operating successfully. The low population base of many regions results in the landfill site being too small for an economically viable system. Concerns over methane production, a greenhouse gas being released to the atmosphere may encourage future investment incentives.

**Biodiesel**

Blending tallow esters with wider-cut middle distillate fuel at the refinery to maintain the cetane value of the power quality diesel fuel is worth further investigation.

The main constraints for vegetable oil esters are low yields of oil/ha and land availability.





## 3.7 References

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## 4 *Power from Water*

Large hydro power schemes are well proven in New Zealand generating over 70% of the electricity supply. The Clyde dam on the Clutha River is the most recent large hydro scheme and the most expensive.

This section does not consider future large hydro schemes and these were well documented in the Ministry of Commerce “Renewable Energy Opportunities” report, 1993. Instead, it considers the potential for small hydro schemes (1 to 10 MW) but also includes mini- and micro-hydro (< 1 MW).

The section on tidal, wave and ocean currents outlines the longer term potential for these technologies around the coasts of New Zealand.

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Annex 4.1 Potential small hydro schemes in New Zealand

Annex 4.2 Wave data analysis example

# 4.1 Small Hydro Power

## 4.1.1 Technology Review

### **Technical status**

Small hydro development has been a source of electricity supply in New Zealand since the beginning of the century. Before that, water power devices for pumping and irrigation were first recorded more than 2000 years ago. By 1800, the water-wheel was being made obsolete by the coal-fired steam engine, but by 1900 water power was back in vogue: the electricity industry had developed; the water turbine had been invented; and the first hydro power station was opened in 1881 in Godalming, England. Commercial hydro power in New Zealand is in a position to be able to continue to develop as a result of improvements in key plant components and advances in applications. Design improvements in turbines and draft tubes have increased operational energy conversion efficiencies. These changes have made it economical to upgrade old marginal stations or recommission previously abandoned plant.

Although hydro power is perceived as a commercial and mature technology, research and development continues with:

- more cost effective methods for selection of sites, plant design and construction;
- innovative civil works and construction materials, particularly for remote site application including modular component and dam construction techniques, non-dam diversions, and the use of synthetic lining and filter materials; and
- development or improvement of cost-effective generating equipment including axial flow turbine packages, ultra-low head turbines, submersible turbo-generator packages, variable speed or induction generators in off-grid applications, and automatic controls and design standardization.

In this report, the emphasis is on small-scale developments (1 to 10 MW), but mini- and micro-hydro systems are also addressed. A mini-hydro system of <1 MW is sufficient to supply a small community. It can be locally organised but some specialist operational input will be required. A micro-hydro system is usually self-contained in that it provides power for a sole owner (such as a rural tourist lodge manager) who would also operate the system. The total potential of mini- and micro-hydro systems is likely to be much less than from small hydro schemes.

## 4.1.2 System Elements

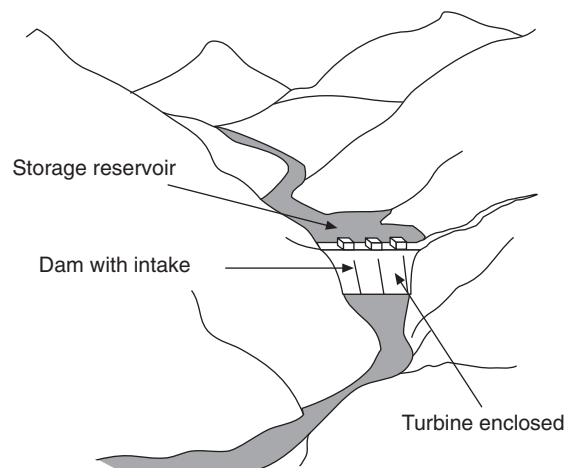
Small hydro power schemes can have similar components and structures to large scale systems (see Figure 4.1). However, they are usually designed for run-of-the-river situations, thereby avoiding the large costs associated with the construction of dams and spillways (see Figure 4.2).

Typically, small hydro schemes consist of diversion structures, a powerhouse, monitoring and control equipment, and transmission equipment to distribute electric power. The elements are generally a scaled down version of those associated with conventional, large, hydro power plant (see Figure 4.3). More specifically, they comprise:

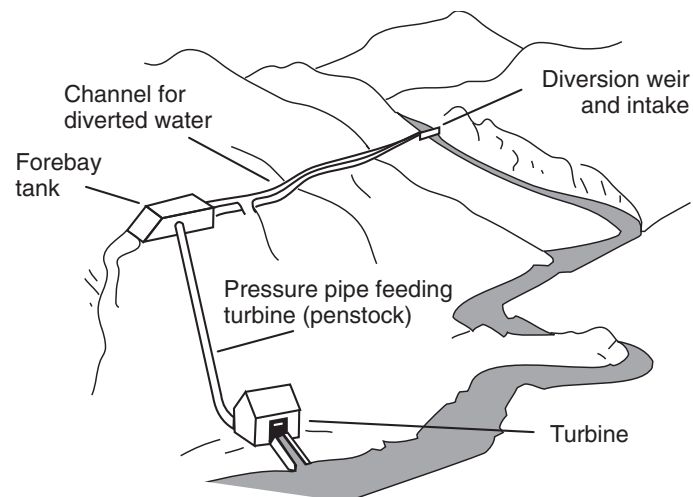
- diversion structures — dams or weirs, intakes, canals, pipelines and penstocks; and
- powerhouse - containing turbine, speed regulator, generator (to convert mechanical energy to electrical energy) and monitoring and control equipment.

Figure 4.3 shows a small-scale hydro power plant, in this example generating power for a single end user, although it could also be used to supply a community. Most small hydro power plants provide systems for monitoring water quality, flow rates and diversion levels as a consideration for plant safety and any environmental concerns.

Micro-hydro systems also have a diversion structure and powerhouse, usually for a pelton wheel turbine, although low-head, high-flow systems are under development.



**Figure 4.1: Hydro scheme with storage (Harvey, 1993)**



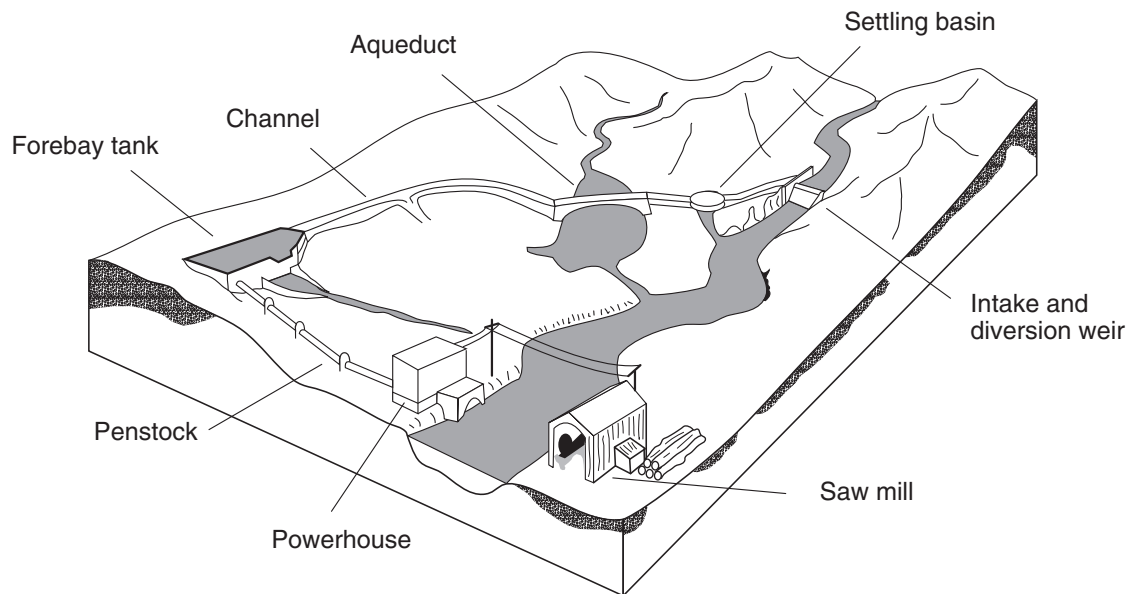
**Figure 4.2: Run-of-the-river micro-hydro scheme (Harvey, 1993)**

### Systems and applications

Small hydro power systems are normally used to provide electricity for the national grid or to supply a local grid. Micro-hydro systems are generally developed for private requirements, including displacement of generation by petrol or diesel engine sets. The systems can be classified as follows:

- **Dedicated power.** The output can be dedicated to a specific (private) user, e.g. a factory or tourist lodge, and could take the form of electricity generation or motive power directly driving machinery. The latter application is not common today, but was the major application of the traditional water-wheel as used by old grain mills.
- **Grid power.** The power generated supplements existing grid supply sources as a small base load or can be designed to offset peak load demands to receive a premium price.
- **Run-of-the-river.** These schemes have very limited storage capacity. Their output depends on river flows and will therefore vary accordingly.
- **Storage systems.** The provision of a dam for reservoir storage enables high flows to be impounded for use during low flow periods. Power output in excess of low flow limits can be achieved.

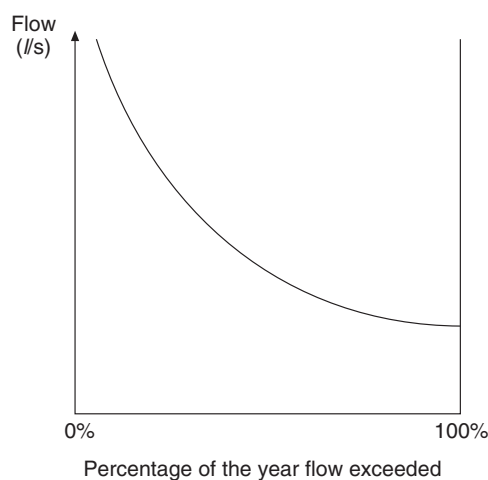
- Pumped storage. This entails the use of energy from other sources (e.g. hydro, wind, thermal, etc.) to pump water from storage downstream of the powerhouse to the headwater storage. The water obtained can be used for peak power demands or to smooth out variations in the grid power supply system.



**Figure 4.3: Major components of a micro-hydro scheme (Harvey, 1993)**

### ***Application limits and synergies***

The main limitation on small and micro-hydro schemes that are not integrated within a grid distribution network is their vulnerability to variations of inflow and therefore the possible need for a backup source of generation and/or battery storage. In designing a hydro scheme it is important to know the variation in flow rates for an average year (see Figure 4.4). Run-of-the-river systems can be susceptible to short term outages arising from damage to diversion intakes through floods or bed load movement. The New Zealand national power grid system comprises significant large hydro and thermal resources. These will provide a buffer for any pessimistic outage scenario associated with the development of all identified potential small hydro sites. Wind power will provide an additional buffer in the future.



**Figure 4.4: The flow duration curve averaged over several years**

The synergies associated with small hydro power systems are more limited than those of large hydro schemes. Small hydro developments generally make little impact on their host rivers. A run-of-the-river diversion scheme will have little influence on flood regulation and the relatively small size of any related storage scheme

would limit its flood control capabilities and potential to offer water navigation opportunities. Bridging of a river may be available in combination with some hydro developments and irrigation projects may also be able to be combined with the hydro investment. The combination of small hydro systems with other energy sources is also possible, such as wind power to provide pumped storage in order to either re-use the water or to meet peak power demands for short periods. Thus, the flow duration characteristics of wind farms complement hydro such that a harmonious interaction is possible. However, in the present marketplace, it would be difficult to take full advantage of this potential synergy unless differential tariffs are revised or individual customers with suitable demand patterns and cost structures can be identified by an interested generator.

### **4.1.3 New Zealand Experience**

New Zealand currently has 17 hydroelectric stations smaller than 10 MW in the North Island operated by supply authorities or power companies with a total installed capacity of about 44 MW. In the South Island there are 27 stations operated by supply authorities or power companies with a total capacity of about 82 MW. Thus, the total capacity of stations smaller than 10 MW including an unknown number of privately owned micro-hydro schemes is close to 130 MW.

With the cheapest large-scale hydro power developments having already been constructed, particularly in the North Island, it is recognized that the small hydro resource may now offer energy generation which is economically competitive in comparison to other forms of generation. This type of development has the advantage of limiting the financial risk to manageable proportions. By commercial terms alone, provided that a hydro power development meets the economic criteria, its development should proceed. With the development of deregulated, more competitive electricity markets, lower generation costs will be sought which may lead to more interest being shown in smaller generation units. This in turn may lead to greater decentralisation of generation facilities. In such a business climate smaller hydro power should look more attractive than it does at present, though there will be increasing competition from gas, cogeneration and wind power.

### **4.1.4 The Current New Zealand Hydro-energy Resource and Potential**

The energy from hydro power is dependent on topography (giving storage and head) and weather conditions (giving rainfall and river flow). In New Zealand water resources vary widely in regional and local patterns of availability. The energy resource is specific to each site location and the merit of developing the site will depend on the available head, the flow conditions and the engineering issues.

In New Zealand the current installed capacity for large hydro power schemes of size greater than 10 MW is just under 5000 MW with an additional potential resource of about 10,000 MW as described in the Ministry of Commerce report, *Renewable Energy Opportunities for New Zealand* (May 1993). In comparison, for small hydro power systems of less than 10 MW, the current installed capacity is 126 MW with an estimated additional potential resource of about 930 MW.

#### **Quantity of resource**

Small hydro studies were undertaken in the late 1970s and early 1980s for the NZ Energy Research and Development Committee (NZERDC) and for the Ministry of Works and Development. The results of the 27 regional reports compiled for these studies have been summarized into two reports (Electricorp, 1989 and ECNZ, 1992) prepared by Works Consultancy Services and the Technical and Development Group of ECNZ. The details of each regional report were updated, mainly in the costing analysis. The most attractive option was selected where a number of alternative developments were possible. It should be noted that the regional reports were quite variable in the way the findings were developed and presented. A list of the station capacities and cost information (updated to September 1995 NZ dollars), used in this report, is given in Annex 4.1 with a regional summary given in Table 4.1.



For the estimated installed capacity of each station, a plant factor of 50% was assumed. Many of the regional reports included schemes larger than 10 MW of installed capacity. These have been excluded from this review. In addition, it will be seen that there is a reduced capacity included in the more expensive power price (Tables 4.2 and 4.3). This was because in the earlier review, schemes of greater than \$7350 per kW (September 1995 dollars) were excluded as being too expensive for development. This has not been re-evaluated, but will have little impact on the identification of the total practical resource during the next decade.

### **Location of small hydro resources**

Table 4.1 shows the location of identified small hydro resources by region. Approximately 60% of the sites are located in the North Island. The distribution of the individual sites throughout New Zealand can be obtained from the summary tables in the Annex.

<b>Hydro resources of New Zealand</b>	<b>Number of potential schemes</b>	<b>Potential development (MW)</b>	<b>Potential energy output (GWh pa)</b>	<b>Capital cost (\$ million)</b>
Northland	5	21	107	134
Waikato Valley Authority Area	25	130	568	539
Bay Of Plenty	9	58	N/A	244
West Poverty Bay	3	13	57	75
East Cape	2	11	50	70
Taranaki	5	30	130	205
Rangitikei-Wanganui	20	116	463	487
Wairoa	4	21	90	131
Hawkes Bay	5	27	116	149
Dannevirke	2	9	40	56
Horowhenua	3	18	81	114
Wairarapa	8	47	205	256
Wellington/Hutt Valley	6	28	121	139
Schemes associated with ECNZ installations	4	26	142	75
<b>Total North Island</b>	<b>101</b>	<b>553</b>	<b>2169</b>	<b>2674</b>
Nelson	5	26	114	87
Marlborough	5	25	108	103
Buller	5	18	76	77
West Coast	17	108	531	531
North Canterbury	5	29	127	127
Central Canterbury	1	9	38	50
South Canterbury	3	16	71	98
Waitaki	7	35	165	157
Otago	11	56	239	216
Otago Central	13	50	220	150
Southland	1	6	25	24
<b>Total South Island</b>	<b>73</b>	<b>377</b>	<b>1713</b>	<b>1622</b>
<b>Total New Zealand</b>	<b>174</b>	<b>930</b>	<b>3882</b>	<b>4296</b>

**Table 4.1: Potential small hydro electric schemes (1 to 10 MW installed capacity) in New Zealand**

### ***Variability of supply***

Large hydro in New Zealand is a reasonably reliable supply having a storage of about 15% of its annual output to remove the impact of seasonal variations. Small hydro resources are, as a whole, more susceptible to river flow variations on account of their generally smaller storage potential. Reliability of supply would normally have to be assessed on a site by site basis.

Where small hydro schemes are integrated within a grid which provides support from other sources of generation, a higher level of supply variability may be accepted and therefore economically feasible.

### ***Changes in supply levels***

The identified potential resource from small hydro is unlikely to change significantly over the next 10 years. The variable factor in small hydro supply is the question of whether a proposed scheme is developed or not. This will depend largely on the cost of development and the market prices for the energy produced at a given time. Parallel uses for the water, such as power generation and irrigation schemes will also have an influence, but are hard to quantify to add to the total potential. For example, most of Palmerston North's water supply is stored in the Turitea dams. Approximately 30,000 m<sup>3</sup>/day is used and a considerable head (of around 40 m) exists between the upper and lower dams, and a similar head again between the lower dam and the water treatment plant. The power generation potential using existing water flows is worthy of investigation.

As a broad estimate, the likely economic development of small, mini and micro-hydro power schemes during the next 10 years will be in the order of 50 MW.

Whereas it can be assumed that advances in technology will progressively reduce the cost of small, mini and micro-hydro development for a given site, the path the energy market follows is much less certain and is likely to be the over-riding influence on changes in small hydro supply in the future. To be successful, a proposed scheme will need to have low environmental impacts, be efficient, and continue the New Zealand tradition of providing innovative engineering solutions to environmental problems.

## ***4.1.5 Environmental and Social Aspects***

It has not been possible to categorize the large number of potential small hydro schemes in respect of their environmental impact, because a standardized method of assessment has not been established. Comments on environmental impact are noted for some specific schemes however, as annotated on the summary tables in Annex 4.1. While development of some schemes may meet strong opposition, a careful assessment of environmental effects should allow environmental issues to be thoroughly examined.

Small hydroelectric generation is mostly seen as a clean, safe and non-polluting means of producing power. Small hydro development does not engender the same spectre of hazard from dam break failure and flooding as with large hydro developments.

However, hydro development does alter the form and flows in rivers. This may interfere with or prevent other uses and values of the river such as scenic values, fish use, stock water supply, wildlife habitats, minimum water flow and recreational uses. Sediment balances can be altered and ecological effects may extend to coastal environments. Increased residence time through storage can create water quality problems, especially where inflows carry high nutrient loads. However, with small schemes, it should be possible, with careful consultation with all groups and individuals concerned, to achieve compromise solutions which provide maximum benefits and minimise impacts. Construction impacts can affect local communities and facilities. In addition, there may be concerns about the visual intrusion of the water intake, the dam or weir, and the turbine building. On the other hand hydro power development does create new recreational facilities, different habitats and form lakes which may contribute to landscape values. Overall, development is a matter of balancing losses with gains such that the resource is shared on a planned basis, for example with canoeing/rafting enterprises. There is an increasing body of information and experience on what is possible and acceptable.

Resource consent activities will affect not only the route to completion of any particular proposed hydro scheme, but also will determine its economic viability. The most significant consent addition is likely to be

imposition of mandatory residual flows downstream of any diversion. For a small hydro proposal this condition might remove a significant portion of the potential energy, which is high in proportion to the fraction of the design flow represented by the residual flow because of the shape of the flow duration curve (see Figure 4.4).

Other factors which may impact on capital costs or operating regimes include screen design parameters; access limitations through private land, forest parks or reserves; and, recreational users such as kayakers. Imposed conditions are likely to increase the economic parameters for the project. In addition, the time input required for the consent process must be factored in to development costs. Consent application procedures can no longer be considered a delay to the overall development process, but as an inevitable and integral component of the overall project development.

For additional information on the planning and environmental issues, refer to EECAs *Guidelines for Small Hydro Developments* available in October 1996.

In the global scene it is interesting to note that the financial world is starting to rethink its positioning on investments and cover for projects which will compound or reduce global warming and other environmental problems. On that basis, the relative competitiveness of hydro power against other forms of energy production may be set to shift. Greater recognition of the consequences of thermal power generation are needed if this shift is to be hastened.

## 4.1.6 Economics

### ***Present supply costs***

Information on current supply costs for small hydro schemes is not readily available. Following the incentives provided under the 1977 government policy to encourage local hydro schemes, thirteen medium to small hydroelectric power schemes were built by electrical supply authorities between 1977 and 1984. These schemes ranged up to 30 MW and were constructed at a cost in excess of \$300 million. The aggregate power cost for all the schemes came out at 12.7 c/kWh (September 1995 prices) compared to the new cost of supply by the state which was estimated at that time to be about 11 c/kWh in 1995 prices (Electricorp, 1989). For the seven schemes of installed capacity less than 10 MW, the production costs ranged from 4 c/kWh to 21 c/kWh. Without the incentives then provided by the Crown, most of these schemes would not have proceeded.

### ***Future supply costs***

#### ***Capital and operating costs***

The details regarding the identified schemes, their capacity, output and cost are contained in the small hydro tabulation presented in Annex 4.1. Schemes with capital costs greater than \$7350 per kW (September 1995 dollars) of installed capacity were excluded on the basis that they would be unlikely to be developed.

The estimated costs from the individual small hydro reports have been adjusted to give a total capital cost in September 1995 terms. The capital costs include not only direct construction costs but also indirect costs such as establishment, construction infrastructure, engineering and project management costs. The estimated costs do not include provision for additional costs likely to be incurred to prepare for and meet the Resource Management Act requirements which have been introduced since the studies were undertaken. These represent an additional discouragement to potential development.

Assessment of the present value of the construction cost depends on the construction period and the distribution of costs over that period. For the small hydro stations a three year construction period to first power generation was assumed. The distribution of the total construction costs was taken to be 35%, 50% and 15% for each of the three years.

For the annual operating and maintenance (O&M) costs, experience shows that these can be adequately represented by a relationship with the construction costs to provide an estimate for the annual O&M costs. For this study the expression used was:

$$\begin{aligned}\text{Annual O\&M costs} &= \text{Total construction costs}/2000 \\ &= 0.05\% \text{ of total construction costs/year}\end{aligned}$$

The economic life for each power station was assumed to be 50 years. Major repairs or refurbishments to individual stations cannot be predicted and in the overall system can be considered to be included in the regular O&M costs. Zero salvage value at the end of the station life was assumed. It is more likely that a major refurbishment may be undertaken but the cost for this effectively becomes part of the construction cost for the new station. In any event the present worth value is insignificant with a 50 year station life.

### *Estimated overall costs*

Using the above calculations the total station installed capacity (in MW) for different cost ranges was obtained and is shown in Table 4.2. Three cost ranges were used — 5 to 10 cents/kWh, 10 to 15 cents/kWh and greater than 15 cents/kWh. The above costs include all local transmission costs to the nearest Trans Power substation or supply authority distribution system. It was assumed that small hydro stations would be relatively close to an appropriate substation so the transmission costs would be only around 1% of the total costs ranges. With small hydro systems no consideration needs to be given to their impact on the main grid system, assuming that their output can be used locally.

Category  Energy Cost Range (c/kWh)	Existing Capacity MW	Potential Capacity MW 5 - 10 c	Potential Capacity MW 10 - 15 c	Potential Capacity MW > 15 c	Total Potential Capacity MW
Total North Island	44	160	264	129	553
Total South Island	82	155	206	16	377
Total New Zealand	126	315	470	145	930

**Table 4.2: Existing and potential installed capacity in schemes from 1 to 10 MW in New Zealand**

The annual power output as assessed in the individual source reports is presented in Table 4.3.

Category  Energy Cost Range (c/kWh)	Existing Annual Output GWh	Potential Output GWh 5 - 10 c	Potential Output GWh 10 - 15 c	Potential Output GWh > 15 c	Total Potential Output GWh
Total North Island	180	601	1032	537	2170
Total South Island	340	708	934	71	1713
Total New Zealand	520	1309	1966	608	3883

**Table 4.3: Potential annual output (GWh per annum) for small hydroelectric stations (1 to 10 MW installed capacity) in New Zealand**

### *Reliability of cost estimates*

Studies for small hydro construction projects are conducted at several levels of detail. The most basic (and crude) level of investigation is that of resource identification. For most such studies, no costs are assigned at that level. The studies in the small hydro series were commonly at resource identification level and therefore should only be considered as a general guide to actual construction costs. It is not possible to even indicate likely costing accuracy at this stage and it is therefore not practical to rely on the cost figures too heavily. It is only when more serious consideration is given to a proposed scheme that a higher level investigation pre-feasibility study would be carried out resulting in more dependable but still crude estimates of construction costs. Cost estimates initially assigned to schemes in the small hydro reports were indicative only, and are most appropriately used to assign schemes to cost bands equivalent to say, low cost, intermediate cost and high cost. In this report, these three cost ranges have been presented.

### **4.1.7 Constraints and Opportunities**

The obvious constraints to the development of a specific small hydro resource are related to the scheme location and engineering and environmental issues. Remote locations increase construction costs including transmission line costs and power losses. Location plus head, flow and geological conditions affect the cost per installed capacity. Flow, storage and capacity choice affect the degree of station utilization, the other key economic element. The opportunity for actual development is then governed by the current/projected market supply and pricing structure for power, which remains the main trigger for a scheme to be developed.

Potential small hydro schemes have been identified at a number of sites throughout New Zealand and are available in a wide range of power outputs. Therefore the possibility to select individual schemes to suit load needs exists. However the development scale that provides the least cost per unit of energy output may not match the expected near term increment in load demand. Also, an available site is most unlikely to be in the location of the needed load. Consequently the opportunity for development may not always be predictable.

An opportunity for small hydro is its positive interaction with other energy sources, for example as a means of storage with wind power systems. This needs further consideration. In addition, the efficiency of operation could be increased if spinning reserves could be reduced by improved management.

A constraint is that for schemes with any associated environmental risk, venture capital investment will be discouraged. The public perception of the impact of small hydro schemes in the environment is not known, but will be site specific.

### **4.1.8 Further Research Requirements**

The first comprehensive examination into the potential of small hydro was commenced in the mid 1970s in response to the oil crisis. A standardized method of assessing hydro potential for schemes from 0.5 to 50 MW was developed and applied to New Zealand based on power board boundaries. These reports remain the primary reference for small hydroelectric potential and form the basis for nearly all subsequent consideration of development. Summaries of this information provided the source for this 1 to 10 MW hydro review. However, there are some gaps in the data base used, notably in the region under the jurisdiction of the Dunedin City Council. The report for this area was based on a different methodology and did not allow for simple comparison with the other reports. This information needs to be reassessed. Stewart Island was also not included in the South Island summary report.

In addition to these small hydro reports, there exists information in reports prepared by WORKS Consultancy Services Ltd. However, the data for these additional potential schemes did not include development costs. Hence, these schemes are excluded from this review as it is not possible to provide compatible ranking without cost data.

An update and review of the existing national reports on small hydro potential should be undertaken to provide validation of the scheme assessments originally prepared in the contributing reports; to allow inclusion of additional work; to include earlier work that was omitted; and, to allow deletion of any recent schemes that have been developed or abandoned.

A review of this kind would also provide the opportunity to undertake a rationalized assessment of each scheme. Features including type of scheme, construction difficulties, environmental impact, remoteness could be categorized and presented systematically along with the updated cost information and environmental assessments.

Compared to possible shortcomings in small hydro development with respect to technological advances or its place in the market, the most important aspects pertaining to its further growth are the reliability of both the engineering and the cost assessments for specific sites. These will ultimately determine commercial success or otherwise.



## 4.2 Wave, Tidal & Ocean Current Power

Wave, tidal and ocean current power represent a significant worldwide future energy source.

Tidal power generation is deterministic in nature and utilises traditional power generation technologies. Tidal generation plant is more efficient with greater high/low tidal differentials. For New Zealand's relatively small average tidal range, it is considered uneconomic in the medium term (ECNZ, 1994a).

Ocean current generation, whilst tidal flow dependent, does not necessarily depend on this physical high/low tidal difference. It is a relatively new generation technology and still requires considerable resource and applied research to create future opportunities in New Zealand.

Wave power is applicable to a wide range of onshore and offshore resources. The resource is of a stochastic nature and is therefore technically more challenging than tidal and ocean current power generation. Wave power generation can utilise a number of different technologies and is thus more flexible in application.

This section will provide a brief overview of tidal and ocean current, but will concentrate primarily on wave power opportunities within the range of New Zealand's shoreline. The supply of energy from thermal gradients in oceans was not considered relevant to New Zealand waters as both the depth of the sea bed and sea surface temperature are too low to contemplate this option (see section 2.5.3).

### 4.2.1 Technology Review

#### *Tidal*

##### *Technology status*

The world's oldest operational tidal power plant is the 240 MW system at La Rance, France. This was installed in 1968 and has an annual net output of 500 GWh. Other operational tidal power plants include:

- 20 MW at Annapolis, Canada
- 5 MW at several other stations in Canada
- 400 kW experimental unit at Kislaya Guba, ex-USSR.

All these sites commonly exhibit large tidal ranges in the range of 3 to 8 m. Good potential tidal sites in the Severn and Mersey estuaries also exist in the UK, though it was recently announced that all further research funding into both tidal and wave power will stop. Good global sites for tidal development are shown in Figure 4.5.

Tidal generation plant has to be designed to handle relatively large volumes of water over short periods and is therefore capital intensive. Novel technologies have been suggested in order to reduce the high capital costs. These include using compressed air to drive air turbines instead of conventional hydroturbines; using magneto-hydrodynamic generators for direct conversion of the energy of a tidal current into electrical electricity; and, replacing a conventional rigid dam with a flexible barrier constructed from synthetic fibre and plastic in order to concentrate the tidal current utilised by the two previous possibilities (Gorlov and Zou, 1989). These concepts have not been developed beyond the demonstration stage. There are no known unique tidal generation technologies being developed in New Zealand.

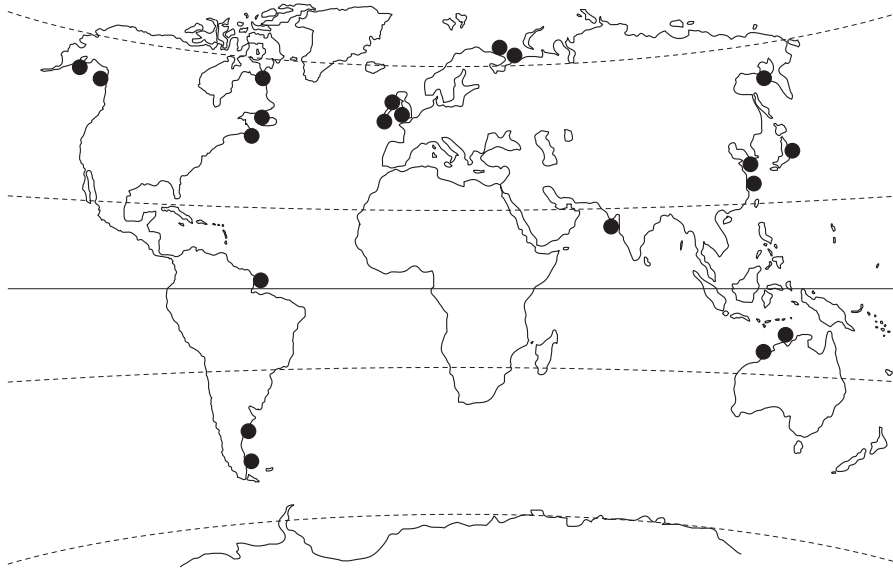
##### *System elements and scale*

Tidal generation plants have potential for large scale MW generation capabilities as exemplified by the 240MW La Rance plant.

Studies have identified similar large scale tidal plant sites in New Zealand. For example an Otahuhu tunnel



connection between the Hauraki Gulf and Waitemata Harbour has a 100 MW potential, but with mean sea level ranges of 2.37 m (compared with the La Rance plant which has a mean tidal range of 8.2m), this cannot be economically developed in the foreseeable future.

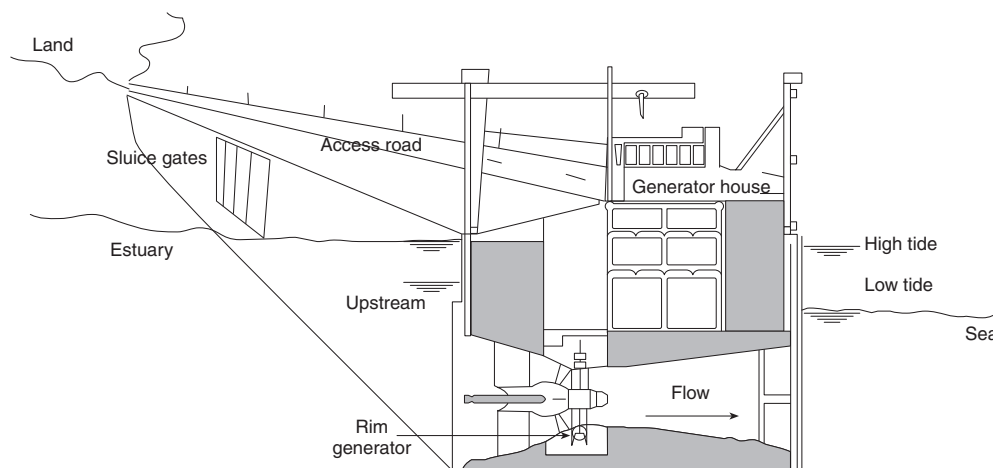


**Figure 4.5: Principal sites for tidal development**

### *Systems and applications*

Proven tidal power systems are tidal barrages that use the traditional hydro electric storage method. For this system, a basin is filled at high tide and later water is allowed to flow out and thereby generate power (using a similar principle to a hydro electric dam).

A basic sketch of a tidal barrage is shown in Figure 4.6.



**Figure 4.6: A typical tidal barrage system**

Variations on this method allow the generation to occur on the incoming (flood) tide or to have a combined solution where there is electrical generation on both the ebb and the flow tides. This latter approach is known as the single basin double effect. These types of systems are best suited to natural tidal “narrows” at the mouths of estuaries or rivers.

### *Limits of systems and synergies*

Since the patterns of tidal movement are produced by the interaction of the moon and sun, they can be predicted with great accuracy. However, as the direction of the tides changes every 12 hours 25 minutes, power

generation will not always be synchronised with a daily power demand curve. Therefore, the plant cannot take advantage of economically advantageous peak demand periods.

The biggest obstacle to development of tidal power is the relatively high capital cost for low utilisation i.e. initial capital costs are high in relation to the energy output produced by the plant. Tidal power plants typically would operate with capacity factors of between 23% and 37% (compare a typical hydro plant with 45% to 65% capacity factor). This is due to generation only being possible during part of each tidal cycle.

Tidal power stations are only likely to be built where there are large tidal flows, maximum high/low tidal ranges and where natural submarine features allow construction at lowest costs e.g. estuarine necks, isthmuses. Such sites in New Zealand will be also limited by coastal management policies. There are possible future opportunities to combine tidal generation with large scale aquaculture facilities, gaining economic advantage from the pump/storage requirements of the aquaculture farm operations.

There appears to be little opportunity in the near future for New Zealand to advance tidal generation.

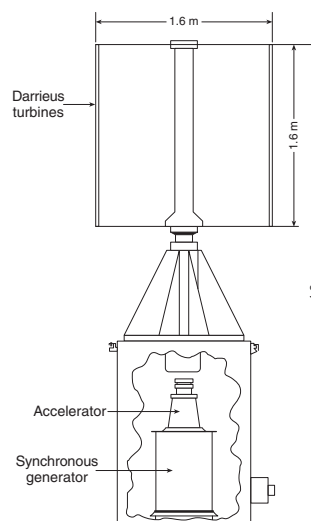
## ***Ocean current***

### ***Technology status***

Whilst international research has been conducted to identify the energy resource from ocean currents, there are no commercially viable technologies for ocean current power generation currently being demonstrated.

Projects which have been undertaken to investigate the feasibility of extracting power from the ocean currents include:

- A 5 kW vertical axis (Darrieus) sea bed mounted device demonstrated in the Kurushima Straits, Japan between 1983 and 1988 (Figure 4.7) and an alternative conceptual vertical axis device (Figure 4.8).
- A 10 kW horizontal axis suspended device tested in Corran Narrows, a construction in Loch Linnhe, Scotland (1992, ongoing) (Figure 4.9) This device had a 3.5 m diameter rotor and was designed to develop 10 kW at a velocity of 2 m/s.
- A 1 kW demonstration facility in the Apsley Strait between the Island of Melville and Bathurst north of Darwin. This facility consists of a suspended horizontal axis propeller turbine which is an adaptation of a river flow water pump (1993, ongoing) (Figure 4.10).

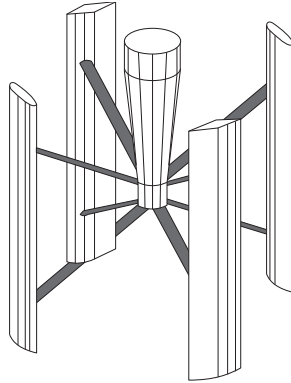


**Figure 4.7: Vertical axis sea bed mounted device tested in Japan  
(5 kW prototype, 1.6 m diameter)**

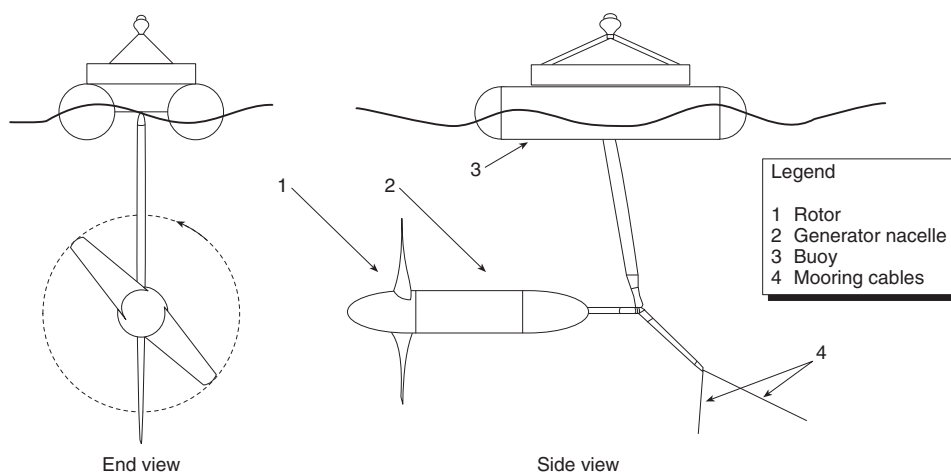
Lessons learnt from these three prototypes were:

- it is possible to extract energy from ocean current velocities greater than 1 m/s;

- long term generation is possible provided marine build up is minimised;
- both horizontal and vertical axis devices are possible, the latter being able to generate power no matter what direction the current is coming from; and
- sea bed mounted or suspended devices can both perform adequately.



**Figure 4.8: Conceptual vertical axis sea bed device**



**Figure 4.9: Horizontal axis device tested in Scotland (10 kW prototype, diameter 3.5 m)**

New Zealand could adapt any of these technologies for close inshore or offshore demonstration plant. There is no known New Zealand technology which will supersede or significantly improve these demonstrated technologies.

In the future, New Zealand may be able to advance ocean current technologies, perhaps using technology developed through high wind generation research, however the first priority is considered to be in researching resource data and site identification.

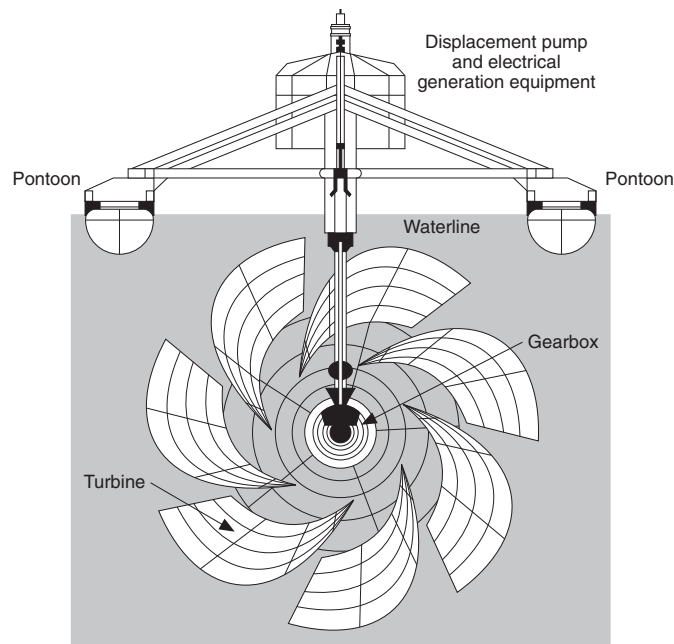
### *System elements and scale*

Ocean current generation is likely to be based upon small scale/distributed plant, similar to small wind turbines and generating 5-50 kW per machine. Prototypes of this scale have been tested in Japan, Scotland and Australia.

The principle drive mechanism is a high-lift, low speed propeller or vane. Large power outputs therefore demand high torque machines, with associated high capital costs.

It is expected that prototypes will continue to be developed in the order of 10 kW output, although a Scottish research program has indicated the size of turbine required to generate up to 200 kW of power would be configured as follows:

- at 2 m/s current a 14 m diameter rotor in a water depth of at least 30 m; and
- at 2.5 m/s current a 10 m diameter rotor and a water depth of 20 m.



**Figure 4.10: Tyson water pump adapted for generation in Australia (1 kW prototype, diameter 1.5 m to 2.0 m)**

### *Systems and applications*

It is expected that to achieve the required ocean current velocity for generation purposes (e.g. more than 2 m/s) sites would be limited to specific tidal “narrows” and channels with high localised sea current characteristics such as Tory Channel in the Marlborough Sounds.

Groupings of a number of small turbines would be required to produce small to medium GWh outputs. This could be compared to a wind farm layout set at the ocean floor or suspended from floating barges. Separation distances between turbines are likely to be less than wind turbines due to the lower current speeds and denser fluid.

New Zealand has potential small scale sites, for which resource data would need to be measured and analysed to confirm the minimum requirements. The data should identify the relationship between current velocity and depth, as well as second order turbulence effects.

### *Limits of systems and synergies*

The ocean current resource will have a similar cyclical period and velocity variation as tidal streams, however this may be less limiting than tidal head difference in terms of generation efficiencies due to the application of different technologies and scale of plant required.

## **Wave power**

### *Technology status*

The main challenge for wave power design and implementation is that the flow of raw wave power cannot be controlled. Therefore, conversion plant has to be able to withstand the worst wave, or be submersible during extreme storms. This problem was recently highlighted with the destruction of a 2 MW demonstration wave power station in the UK within a month of installation. Submersible devices also have the disadvantage of increased difficulties of power extraction and maintenance (Twidell and Weir, 1986).

A 350 kW tapered channel system, manufactured by Norwave, has been operating in Norway since 1985. Other developments or installations include:

- a 500 kW oscillating water column system, manufactured by Kvaerner Brug in 1985, but destroyed in 1989 by freak 20 m high waves;
- 3 wave power plants operating in Japan (at 20, 30 and 60 kW respectively);
- a 75 kW on-shore, gully based oscillating water column test plant in the UK; and
- a tapered channel system evaluated by the HEC Tasmania for their King Island (Bass Strait) facility. However, a wind powered generation plant was the preferred option.

Prototype testing is under way for a new device that is permanently submerged under water. This means that it is protected from extreme waves etc. which is a major advantage in preventing its destruction from chance effects.

Research has been done on piezoelectric devices which generate small electrical currents through simple tension or flexion. This could be applied to provide a self sufficient supply of electricity on navigation buoys. There are two known generic types of application:

- piezoelectric cable — uses tension to generate electricity, as for a navigation buoy; and
- piezoelectric blanket — floats on the surface and generates current from wave motion.

Work on these technologies is at an early stage of development.

### *System elements and scale*

Wave power is likely to be best suited to small- to medium-scale generation, either on-shore or off-shore.

On-shore plant is likely to be limited in size by local coastal topography and the availability of natural shoreline formation. Demonstration plants have been installed in Norway, for example, using the oscillating water column, with power output up to 3 MW. New Zealand has potential for a number of similar 3 MW machines, however coastal policy and resource management issues would feature in such a development.

Alternatively, natural features such as coves could be used for in-shore systems by damming with multiple tapered channel structures. This would be the technically most robust system, although capital costs are likely to be restrictive.

Off-shore or near-shore systems could extend to perhaps 20 MW capacity, utilising multiple tethered or anchored barge-mounted plant. Transmission by submarine cable is a significant capital cost component for offshore systems and limits the water depth where an installation can go.

### *Systems and applications*

There are a number of different wave generation technologies under investigation which are illustrated in Figure 4.11. The generic technologies are:

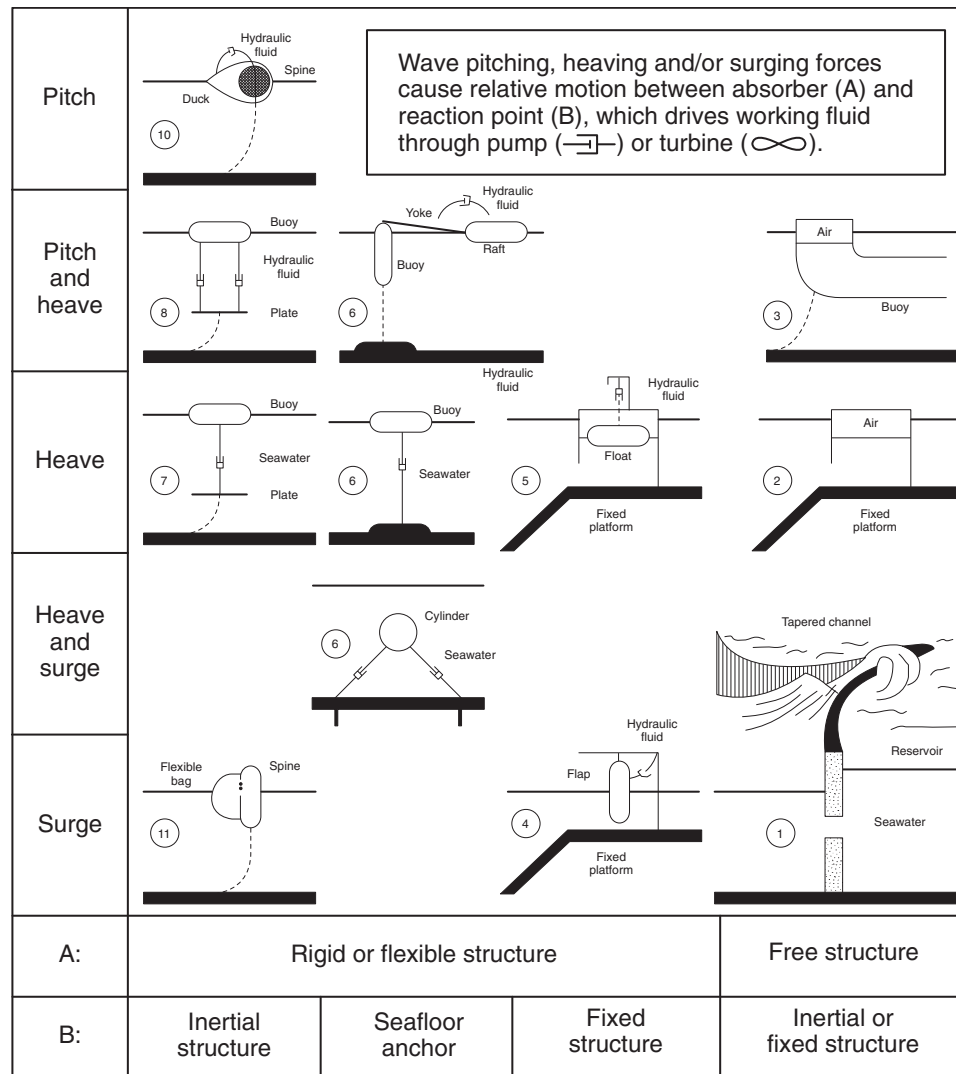
- tapered channel/reservoir systems using traditional tidal or hydro turbine generator plant (see Figure 4.11 (1) and Figure 4.12);
- oscillating column systems using air pressure generated by wave movement to drive turbines (see Figure 4.11 (2), (3) and (11) and Figures 4.13 and 4.14);
- reciprocating mechanised systems that use flotation devices to drive pistons, pumps etc. (see Figure 4.11 (4) to (10) and (12) and Figure 4.15); and
- piezoelectric systems.

### *Limits of systems and synergies*

Waves lose energy as the depth of water decreases, therefore there is more potential energy to be obtained from

off-shore than from on-shore or near-shore power plants. However, technology has not yet been developed that will ensure an off-shore plant will withstand the occasional storm or wave that could destroy it. The most successful plants so far have therefore been tapered channel or other such near- or on-shore devices.

From the resource data measured to date in New Zealand, there is a potential correlation between seasonal variation in wave power and electricity demand i.e. both peak in winter. At high grade sites a reliable base output can be maintained for a large part of the time, having few calm periods.



**Figure 4.11: Examples of wave power processes**

Because of New Zealand's relatively low tidal range, on-shore based wave power plant can be optimised, as water level fluctuations are not too great. This is the opposite to tidal generation plant. Shore based plant could in the future prove ideal for remote location power production and integration with other small scale supplies such as wind.

Large off-shore installations may be limited by major infrastructure issues, requiring substantial investment in undersea cables and land transmission lines. Suitable port development would be needed to construct and float structures and provide a service base (ECNZ, 1993).

Tapered channel systems may also be limited in capacity by the available wave height, much in the same way as for tidal power. As waves enter the tapered channel and surge into the reservoir beyond, turbines are driven by the water that flows out of the reservoir. The amount of water entering the reservoir is limited by the maximum height of the waves/tides while still allowing height differences to drive the turbines on the outflow. Increasing the number of channels per reservoir requires increasing the reservoir capacity to maintain an

optimum outflow rate. The increased cost of having more channels and a larger reservoir quickly outweighs any benefits.

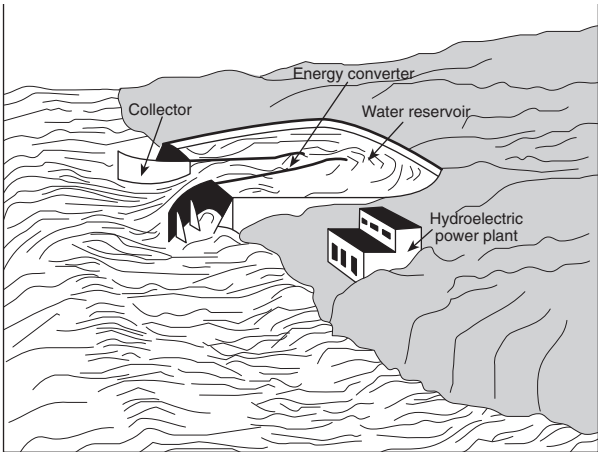


Figure 4.12: Tapered channel system

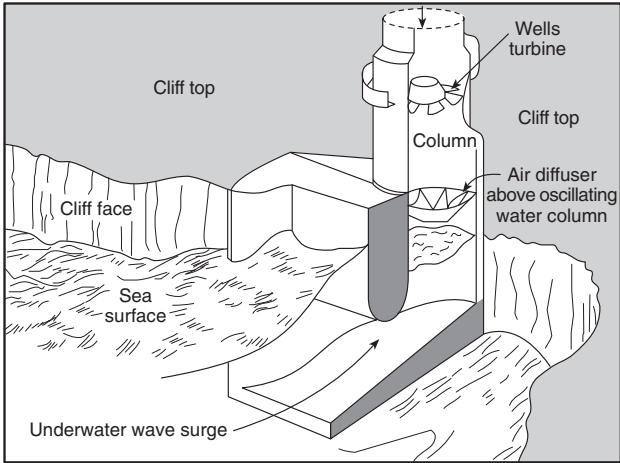


Figure 4.13: Oscillating water column system (Twidell and Weir, 1986)

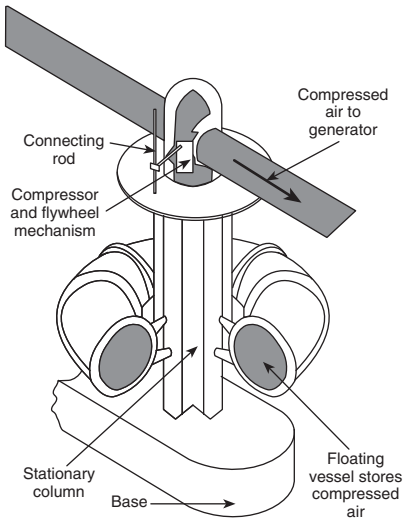


Figure 4.14: MOTO system



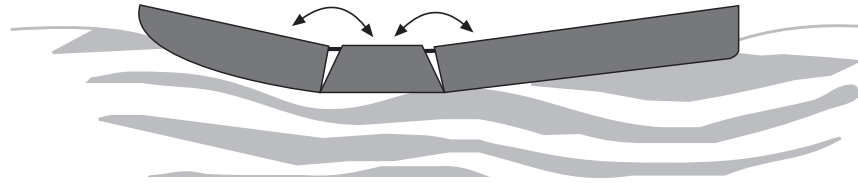


Figure 4.15: Cockrell's Raft

## 4.2.2 New Zealand Experience

There are no known developments for use of tidal, ocean current or wave power generation devices within New Zealand in spite of New Zealand's experience with large-scale hydro generation plant which is particularly suited to tidal generation engineering. It is unlikely that tidal, ocean current or wave powered electricity generation will become commercial before 2005. There may be opportunities to utilise tidal generation in conjunction with aquaculture production facilities, however the economics will be driven by the ability of the aquaculture project to finance a tidal pump/storage facility for water control purposes.

## 4.2.3 Current New Zealand Energy Resource and Potential

### *Tidal*

#### *Resource specification and availability*

The resource is specified in terms of areas with maximum high/low tidal differences. The greater the difference between the high and low tide mark, the greater the potential volume of electricity generation and so the greater the resource. The value of energy that may be extracted from a tidal plant is proportional to the square of the tidal range. Currently and in the medium term, mean tidal ranges of at least 5 m are required for economic development (ECNZ, 1995a). Since the greatest tidal ranges in New Zealand are no more than 3 m, the resource in New Zealand for tidal power is non-existent until such time as technologies are produced which will economically allow energy to be extracted from small tidal ranges.

#### *Resource location*

Should the technology become available to utilise low tidal ranges there are a number of potentially suitable sites around New Zealand's extensive coastline including estuaries, river mouths and coves. Each site would require rigorous environmental impact assessment and under current coastal resource management policy the consents process is likely to severely limit those sites suitable for future development.

#### *Potential supply and seasonal variability*

The tidal range variation for one month for a regular semi-diurnal tide is shown in Figure 4.16.

Power supply from tidal sources is controlled by the ebb and flow of tides (on a 12 hour, 25 minute cycle), by the change in tidal magnitude over half a lunar cycle (spring and neap tides) and, to a lesser degree, by seasonal variations, wind strength and direction, and air pressure. The cyclical nature of the resource limits the potential utilisation.

### *Ocean current*

#### *Resource specification and availability*

The power derived from ocean current can be calculated using the equation for the power existing in a fluid flow which is defined as follows:

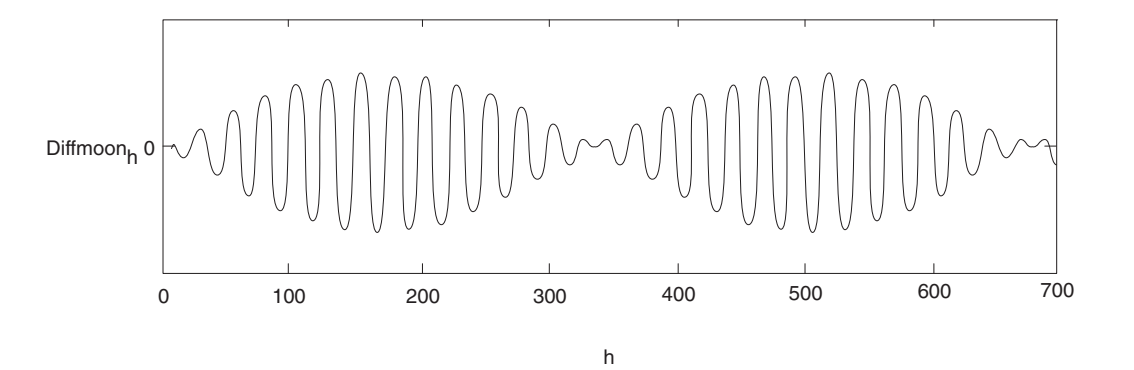
$$\text{Power (W)} = C_r(0.5 \rho V^3 A) \quad \text{where:} \quad C_r = \text{power coefficient}$$

$$r = \text{density of fluid (kg/m}^3\text{)}$$

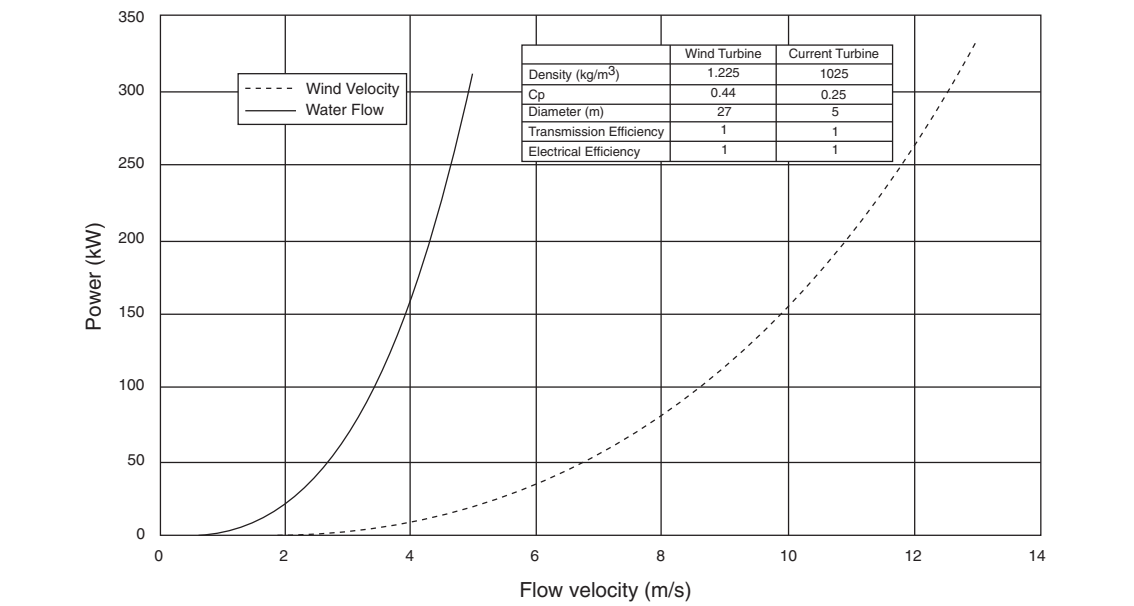
$$V = \text{fluid velocity (m/s)}$$

$$A = \text{area (m}^2\text{)}$$

The ability for ocean current to supply power can be demonstrated when compared with wind power. Sea water is 835 times more dense than air and this has a marked effect on the necessary flow velocities required to generate an equivalent power output, as can be seen in Fig. 4.17. The gradients of the two curves show just how much more critical is the power from the ocean current device on a change in flow velocity.



**Figure 4.16:** Tidal range variation for one month for a semi-diurnal tide (ECNZ, 1995a)



**Figure 4.17:** Comparison between ocean current and wind power generation

*Resource quantity*

The ocean current strengths around New Zealand have not been measured extensively and so the total number of possible sites is not known. Further research therefore needs to be done to assess this. Information that has been gathered has generally been for off-shore projects in specific locations. Also odd measurements at points of interest, such as harbour entrances have been taken, where velocities are important for navigation purposes. Such information is shown in Table 4.4.

These figures are significant when it is realised that for the Scottish prototype a peak current velocity flow of only 2 m/s was considered appropriate. This would suggest that New Zealand has a sizeable resource. However, accurate site selection studies still need to be done to determine the full extent of New Zealand’s ocean current resource.

Location	m/s
French Pass	3.1 +
Tory Channel	3.6
Tauranga Harbour Entrance	2.6 +
Bluff Harbour Entrance	2.1 +
Manukau Harbour Entrance	1.9
Raglan Harbour Entrance	1.5
Whangarei Harbour Entrance	1.5 +
Otago Harbour Entrance	1.5
Karori Rock	3.6
Cook Strait (Terawhiti Rip)	2.1 - 3.6

**Table 4.4: Ocean current strengths at isolated locations in New Zealand**

### *Resource location*

Areas within New Zealand that could contain a superior ocean current resource are in narrow straits, especially where there are localised flows; at entrances to lochs, bays and possibly harbours; and areas where the ocean sea bed is relatively shallow coupled with good tidal changes (ECNZ, 1995b).

From preliminary data, Cook Strait and Tory Channel appear to best satisfy these requirements. Further resource assessment would need to determine for these sites:

- current velocity at varying depth; and
- secondary turbulence effects.

### *Potential supply and seasonal variability*

There is a theoretical relationship of the amount of power generation possible with respect to the velocity of the current flow which is shown in Figure 4.18 (for a 2.26 m diameter turbine, whereas that depicted in Figure 4.17 was 5 m in diameter). It is assumed that current flows would be at their minimum during the turning of each tide and would peak midway between high and low tides, though it is not known what the variations are, due to wind speed etc. Seasonal variation would be minimal with tidal changes expected to be the dominant factor.

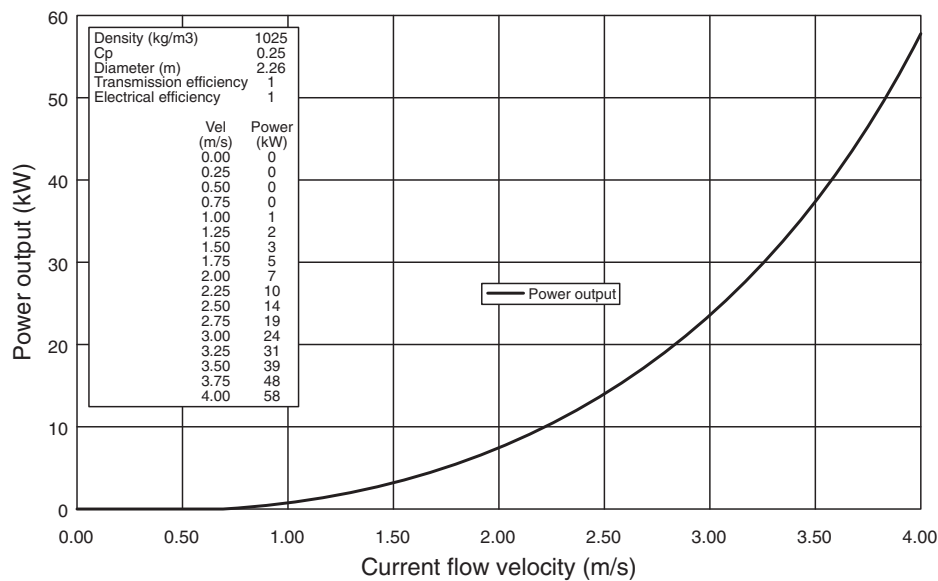
## **Wave**

### *Resource specification*

Wave energy is generated mainly by wind moving over the ocean. It is normally dissipated through water turbulence, counter winds or on contact with reefs and shorelines.

Data obtained from a wave measuring device is usually expressed as the wave period (inverse of frequency) between crests or zero crossings, and the significant wave height (SWH). The SWH for a measuring period is the average of the highest third of the number of waves during the period. The height is measured from the trough to the crest. The wave data can also be given as an energy spectrum, where the energy is given in bands of frequency or period.

When the SWH and wave period data is available the energy in the waves can be calculated. A theoretical formula assumes pure sinusoidal waves of constant period, but in practice the waves are made up of a combination of frequencies. This means that the theoretical formula gives an underestimate. Empirical formulas have been found for particular sites, by measuring the true power and the wave period and SWH. The power is proportional to both the wave period and to the SWH. A sample calculation is shown in Annex 4.2. Only the small, wind-generated waves are considered here. Deep swell energy is more difficult to capture as it tends to occur with greater frequency further from the shore making the system more expensive.



**Figure 4.18: Current flow velocity against power generation output**

### *Resource quantity*

The kinetic energy in waves is large, and New Zealand with its long coastline and large surrounding areas of open sea, has a large potential resource, although the amount of energy which can be practically and economically extracted is low. The wave energy around the New Zealand coastline is probably 30 kW/m length or more in exposed places, which is a good quality resource. A few places within the territorial waters have 50 kW/m power content or more. Wave power could theoretically supply any energy demands we have for the foreseeable future, assuming we were able to overcome significant technical and capital intensive design problems.

The only accurate long term monitoring study undertaken in New Zealand has been at the Maui platform off the west Taranaki coast. Wave recorders have been used there since 1977 (though it is not clear whether they are still in operation (ECNZ, 1995b)). There has also been some short term data collection at several sites around New Zealand. Most of the data on the wave climate around New Zealand is based on visual observations of average significant wave height and zero crossing periods. This data has been converted into wave energy estimates using theoretical models giving first-order estimates of the amount and distribution of deep water wave power levels around New Zealand (Figure 4.19). These estimates cannot be treated as accurate, but the general order confirms that New Zealand has a high wave potential.

Annex 4.2 gives the power calculated from data obtained at a typical site. The average power for two months was calculated to be 63 kW/m, which compared reasonably well with the open sea figures in Figure 4.19.

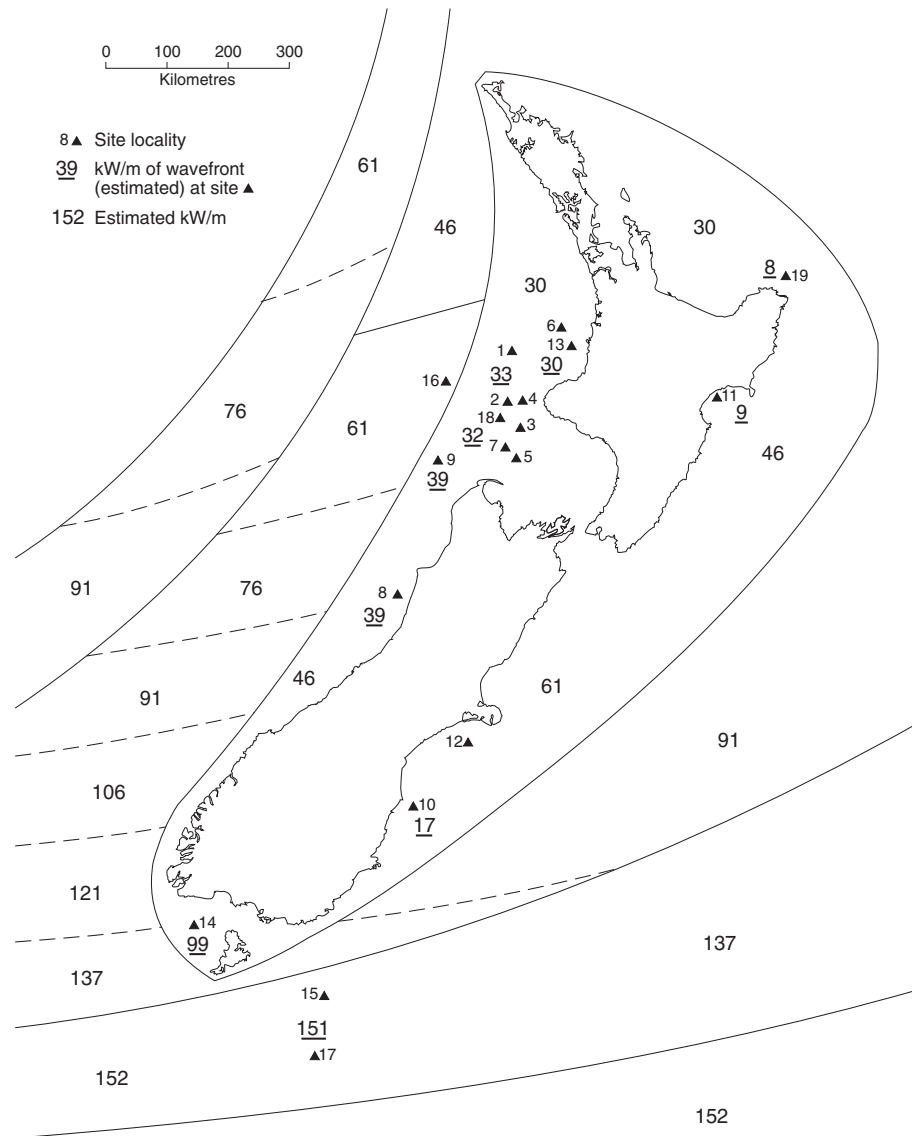
Prototype wave power plants have efficiencies of around 12% to 15%, calculated on an average basis. A practical power plant will have instantaneous efficiencies which reduce to zero at low wave heights. The maximum power output is determined by the most economic size of the generator and cables. There may also be a maximum wave height above which the plant must be shut down to avoid damage. A power curve for a real plant could not be obtained, but Annex 4.2 shows the approximate output from a power plant over a two month period. Hence, for a site with an average wave power of 63 kW/m, the average electrical power generated has been calculated to be 9 kW/m. This is affected by the maximum generation capacity of the power station which, in these calculations, was set to a value of 15 kW/m, a likely value for a realistic power station. Hence, a 500 kW installation would require a collection width of 33 m and would generate about 300 kW on average.

### *Resource location*

Potential wave power development sites around New Zealand are limited by these parameters:

- estimated wave resource (upwards of 30 kW/m);

- proximity to load centre;
- site development requirements;
- optimum conversion types (e.g. tapered channels for smoothed coastlines, oscillating water columns for rocky headlands);
- local and environmental impact;
- Resource Management Act; and
- New Zealand Coastal Policy Statement.



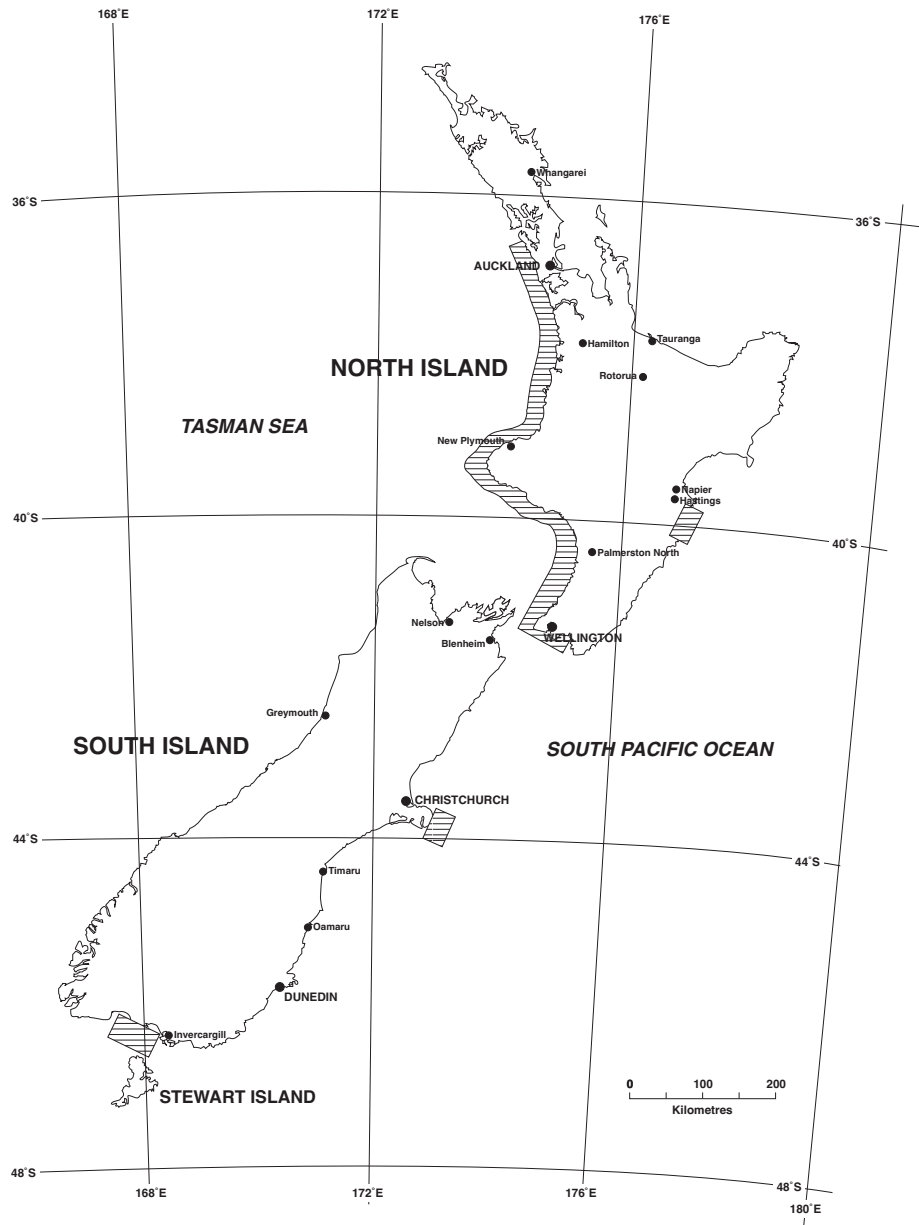
**Figure 4.19: Deep water wave estimates around New Zealand**

The best potential sites, identified by shaded areas, are shown in Figure 4.20. Further wave energy assessment would be required to discover the precise potential. Site issues that would have to be taken into account which are likely to further limit the number of possible sites are:

- present uses of area (e.g. public beaches);
- distance off-shore (only up to 20 km off the coastline will it be viable for transmission of electricity generated back to shore);

- depth of sea bed (due to having to lay down transmission cables under the sea bed to avoid trawlers); and
- areas of cultural significance (in particular areas with dominant natural features).

It is anticipated that the potential area indicated will ultimately be confined to a small number of sites. Only the sites with the lowest installation costs will be viable in the near future.



**Figure 4.20: Potential wave site areas in New Zealand (shaded areas)**

#### *Potential supply and seasonal variability*

The amount of energy that could be derived from wave power is immense, but at present it is not economic to extract this energy. Each 1 km of wave power plant could produce power equivalent to approximately 2% of present energy consumption. There are no prior estimates for potential wave power output at various cost levels for New Zealand.

Seasonal variations match energy demands well, in that in the winter when wave generation is producing at maximum output there is a strong winter power demand. The yearly variation between wave power levels is not large enough to cause major concerns in terms of generation output.

The frequency of occurrences of large waves (in excess of a wave power plant's survival height design) is essential information for the design, location and management of wave plant. This aspect of wave variability is the major concern for long-term reliability and life.

#### **4.2.4 Environmental and Social Issues**

##### ***Tidal***

Site selection of a tidal device would have to consider:

- tangata whenua;
- estuaries, fisheries and ecological impacts;
- recreational use of inland waterways; and
- flooding and land inundation.

##### ***Ocean current***

In selection of a site for an ocean current device these impacts would have to be considered:

- shipping routes;
- marine life in the area with special consideration to larger marine life, e.g. dolphins, seals etc., as well as smaller sea life such as mussels which will tend to build up on the turbine blades and reduce the performance;
- present recreational uses for the area e.g. fishing, swimming, diving etc.;
- existing supply system to which the generation will be linked e.g. remote rural community, national distribution network, remote power application;
- water quality and contaminants which effect the build up of unwanted material on the turbine blades; and
- wave and wind action for surface mounted devices.

##### ***Wave***

Each system must be considered on its own merits. Wave power arrays several kilometres long may have an impact on shipping and coastal processes such as sediment movement due to reduced shoreline wave energy. The impact of some small scale wave power systems is no more than an anchor on the sea floor, which causes minimal environmental impact, whilst large string-like systems can be several kilometres long and can impact on marine life, shipping and the coastline. Siting of shoreline plants would also need to be on exposed rocky coasts below the high water mark, and such land may be regarded as environmentally, aesthetically and culturally valuable (ECNZ, 1995b). Access roads to a shoreline plant may be necessary, along with distribution cables and pylons. If there was a substantial offshore facility there would also be land use and visual impacts from substations and grid connections. The precise effects on marine life off-shore are not known. Construction implications for city ports could be significant. Small-scale or land-based plants may affect local amenities.

The energy supply is clean and non polluting. Under normal working operating conditions there are no chemical emissions. The environmental cost of wave power is low to medium and could be justified by reducing the dependency on other fossil fuel energy sources.

#### **4.2.5 Economics**

##### ***Economic comparison of generation systems***

The economics of tidal, ocean and wave power generation are all site specific and depend on a favourable



resource, natural elements and applicable technologies. It is assumed that each generation type would receive an equivalent market price for the electricity produced. Certain applications could, however, benefit due to the scale relative to the local grid network and remoteness of the demand.

For the purposes of defining the relative economics, each generic generation type was ranked in order of preference based on three key economic parameters:

- capital cost;
- operating and maintenance cost; and
- energy utilisation from known technology (i.e. based on capacity factor — see Table 4.5).

The rankings were multiplied by a relative weighting for each parameter (percentage sensitivity).

Capital costs were ranked based on known hydro, wind and tidal development projects. Ocean current and wave generation costs were assumed from the limited demonstration project data available.

Operation and Maintenance costs for hydro and wind projects are reasonably well known, along with their technical risks. Tidal, ocean current and wave plant ranked lower in economic merit due primarily to the harshness of the environment and the high risk of failure. These factors are inherent economic barriers to constructing and operating electrical generating plant utilising the ocean as an energy source. Energy utilisation ranges were estimated as were the percentage sensitivity for each technology.

Development Stage	Past		Present		Future					
Generation Type	Hydro		Wind		Tidal		Ocean Current		Wave	
Capacity Factor	50%-60%		35%-50%		15%-25%		15%-25%		12%-15%	
	Percentage Sensitivity	Ranking	Percentage Sensitivity	Ranking	Percentage Sensitivity	Ranking	Percentage Sensitivity	Ranking	Percentage Sensitivity	Ranking
Capital	50	1	50	2	50	3	40	4	40	5
O & M	10	1	20	2	20	3	25	4	30	5
Energy Utilisation	40	1	30	2	30	3	35	4	30	5
Weighted Total*	100		200		300		400		500	

\*Weighted total = sum(percentage sensitivity x ranking)

**Table 4.5: Ranking of tidal, ocean current and wave technology economics against hydro and wind power**

The higher the final weighted total, the less favourable the scenario. Indicative results show tidal power has greater future potential than ocean current or wave. The lower economic ranking (i.e. implied higher costs) of wave power compared to tidal and ocean current reflects the stochastic nature of the resource. On some days wave power generation will be nil due to calm seas, whereas tidal flows are consistent due to the effects of moon and sun, whether the sea is calm or rough.

Capital, operating and maintenance costs were also anticipated to be greater for wave power plant than for ocean current and tidal power systems. There is the added expense in order to “overbuild” to ensure the plant will withstand freak waves. The possibility that overbuilding may have an affect on the operational stability of the wave plant is also of design concern.

It is emphasised that Table 4.5 provides only a comparison of common economic parameters for each of the different technologies, not a definitive economic reference.

### ***Tidal***

A study of the Severn Tidal Energy Development in the United Kingdom (UK) (ETSU, 1993) shows cost per unit of energy compared with the tidal range (Figure 4.21) for 21 sites as listed in Table 4.6.

Comparing New Zealand's maximal mean tidal range of 3 m against the trend curve generated by the ETSU study, the lowest estimated cost of energy generation remains at NZ\$0.30/kWh.

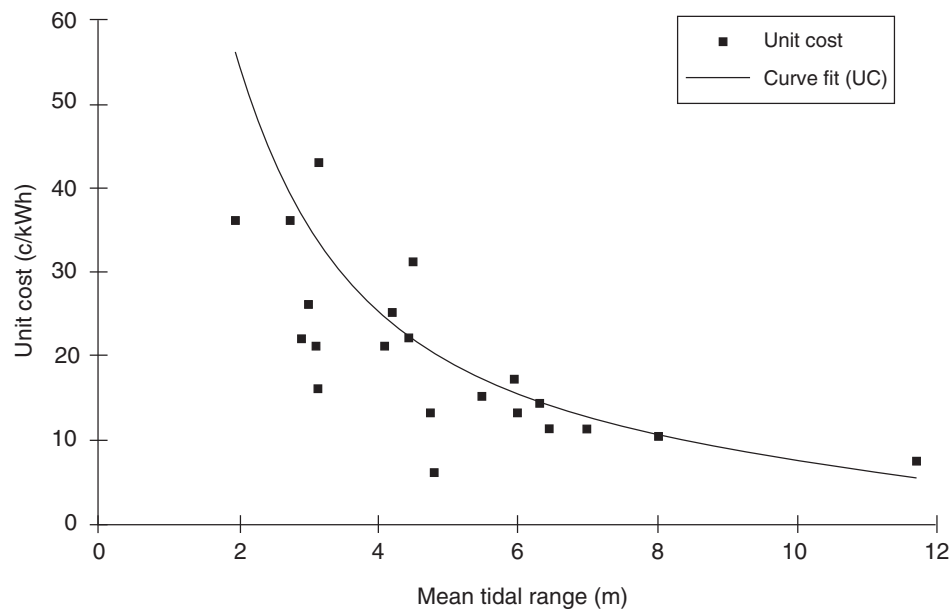


Figure 4.21: Mean tidal range and unit cost (NZc/kWh)

	Mean Tidal Range (m)	Unit Cost (NZc/kWh)
Severn inner line	7	11
Severn outer line	6	13
Morecambe	6.3	14
Solway	5.5	15
Dee	5.95	17
Humber	4.1	21
Wash	4.45	22
Thames	4.2	25
Langstone	3.13	16
Padstow	4.75	13
Hamford	3	26
L Etive	1.95	36
Cromarty	2.75	36
Dovey	2.9	22
L Broom	3.15	43
Milford Haven	4.5	31
Mersey	6.45	11
Fundy Site B9	11.7	7
Strangford Lough	3.1	21
Garolia Bay	4.8	6
La Rance	8	10

Table 4.6: Mean tidal range and unit cost for sites in UK, France and Canada

### ***Ocean current***

At this point in time cost predictions for ocean current technology are not available, as research to date has

not indicated the costs of the projects or the expected cost of generation (ECNZ, 1995b). Indeed none of the prototypes to date has even transported the generated electricity to shore.

Initially, the types of ocean current locations that will first become economic will be remote areas with high power prices in close proximity to the sea, e.g. the Marlborough Sounds. Since wind technologies are already well developed, such areas would also tend to have a poor wind resource or meet a public resistance to wind turbines on the landscape. Another option may be to use both wind and ocean current in conjunction with one another in order to achieve a more uniform load generation curve, but the cost would be high.

### **Wave**

Wave powered plants have been demonstrated and built only in subsidised environments. The risks of technical failure indicate these plants are not yet viable, even when subsidised.

Manufacturers' cost estimates indicate some possible future costs, given their commercially viable production. However, since all the types of systems so far are either one-off prototypes or demonstration plants, comparing the capability of a given system over different sites is not feasible. In the future, as more units are built, costs can be expected to fall. At this stage, it is considered that the cost of electricity generated would be in the order of NZ\$0.50/kWh.

## **4.2.6 Constraints and Opportunities**

The current high level of interest in New Zealand wind power applications is likely to impact on the development of less economically favoured and more technically challenging ocean generation technologies.

New Zealand's relatively well developed and accessible national electrical transmission system represents a constraint to all new renewable electricity generation systems.

Opportunities for these generation systems are most likely to come through identification of remote area opportunities. Remote area power supply systems are already becoming economic and competitively pursued by technologies including solar, wind, hydro and hybrid diesel engine applications. It is unlikely wave or tidal systems could compete within the next decade.

### **Tidal**

The main constraint is the lack of the potential resource due to New Zealand's low average tidal range. This makes tidal power electricity generation uneconomic as a stand alone development plant. Utilising tidal power plant in conjunction with other projects such as aquaculture, may well allow the process (or variations of it) to become commercially viable. The coastal management RMA policy could also be a significant barrier to progressing aquaculture/tidal generation projects.

### **Ocean current**

Constraints for ocean current include the lack of development of the technology, and the lack of available resource data at potential sites. Other likely constraints could be:

- shipping movements;
- transmission and grid integration;
- maintenance of sites; and
- construction environment.

### **Wave**

The principal constraint is to overcome the design problems due to operating in an extreme environment. This results in a lack of readily available, reliable and commercially viable generation plant. At the present time, where electricity is required there are a number of more technically developed and much cheaper options than wave power.

Wave power devices may also have an effect on shipping routes and marine ecosystems. The placing of transmission cables may interfere with fishing operations, though these are less likely to be an issue for a shore-based plant.

Wave power plants, once sufficiently developed, may provide an opportunity for use as breakwaters for harbours or areas prone to erosion. In doing so the plant capital cost is likely to be significantly less if a breakwater has already been built or is already required as the costs are shared.

Early opportunity is for remote applications on navigation buoys and off-shore platforms. Piezoelectric devices have shown potential for those applications, in lieu of solar panels.

#### **4.2.7 Further Research Requirements**

There are future research opportunities in the development of grid integration technologies such as power electronic inverters, storage devices etc. These will need to provide an economic link between new renewables including tidal, wave and ocean currents, and traditional transmission requirements.

##### ***Tidal***

Successful tidal plants, such as at La Rance, have shown that the technology has already been sufficiently developed, albeit in regions with high tidal ranges. Research is needed to determine sites in New Zealand where tidal power systems may be used in association with other applications to make such schemes viable (e.g. operational research into pump storage facilities with aquaculture).

##### ***Ocean current***

Most of the international research done so far has been to determine the resources available in tidal streams and into designing suitable turbines to harness the energy. Developing viable tidal stream power generators is yet to be accomplished due to the limited number of potential sites having strong enough flow velocities to harness a meaningful amount of power.

Further research is required into quantifying the ocean current resource around New Zealand in terms of areas with high energy potential. Research and development of an appropriate turbine would also be useful. There may be opportunities arising from the development of similar wind generation technologies.

##### ***Wave***

More work can be done to collect data from wave rider buoys (or seismic equipment) to provide a more detailed picture of the possible location of optimal wave power collection sites. Once this has been collected, the costs of possible wave power plants can be estimated. A more ambitious project would be to design and build a New Zealand prototype to get a better idea of New Zealand conditions and create our own national supply curve data.

The environmental affects of wave power for marine life as well as for coastal ecologies, such as the estuary and rocky shore, are unclear. They are assumed to be minimal, but this still has to be clarified.

In identifying the resource, research could simultaneously be undertaken to find areas of badly eroded or unstable coastline where wave power plant could be installed in association with breakwaters.



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## Annex 4.1: Potential Small Hydro Schemes (1 to 10 MW) in New Zealand

### North Island

Scheme, Site, River	Generation Flow (m <sup>3</sup> /sec)	Approx. Net Head (m)	Estimated Installed Capacity (MW)	Estimated Energy (GWh/y)	Capital Cost (\$ million)	Cost/kW (\$/kW)	Principal Features	Comments
<b>NORTHLAND</b>								
Taheke Falls, Punakitere River	10.8	28	2.5	11	14.94	5971	Headpond	Depletion of waterfall
Lake Omapere, Utakura River	2.2	120	2.2	26	12.65	5757	Lake storage, long conduits	Downstream flow regulation increase in lake level fluctuation, depletion of waterfalls
Maunganui, Kaihu River	8.09	134	9.0	39.4	58.95	6553	Dam, reservoir, conduit	Water supply, flood control and recreation affects tourism, kauri park, inundates agricultural land
Whatoro, Kaihu River	7.89	64	4.2	18.3	28.81	6877	Dam, reservoir, conduit	Water supply, flood control and recreation affects tourism Kauri Park, inundates agricultural land
Purua Rapids, Wairua River	26.7	13	2.9	12.6	18.51	6406	Barrage	Some regulation for Wairua Falls
<b>WAIKATO VALLEY AUTHORITY AREA</b>								
Waihohonu Stm, Desert Road	13.3	90	10.0	43.8	26.49	2652	Add diversion from Ohinepongo stream	
Waihohonu Stm, Desert Road	11.3	90	8.5	37.2	23.06	2713	Diversion weir; 3 km canal	
Waihohonu Stm, Desert Road	11.3	53	5.0	21.9	17.64	3521	Diversion weir; 1.5 km canal	
Waihohonu Stm, above Desert Road	11.3	51	4.8	21	16.90	3521	Diversion weir; 1.2 km canal	
Waipapa R at Ranginui Rd	5.3	109	4.8	21	18.25	3809	Diversion weir; 0.6 km canal; 1.7 km pipeline	
Mangatoetoe Stm at Aggregate Plant	3.05	90	2.4	10.5	9.73	4073	Diversion weir; 1.2 km canal; 1.6 km pipeline	
Kuratau R at Moerangi	2	145	2.4	10.5	13.22	5493	0.75 km pipeline	
Kuratau R at Moerangi	4.45	100	3.7	16.2	18.03	4844	Diversion weir; 4.6 km canal	
Waitahanui R plus Te Arero Stream	5.4	75	3.4	14.9	14.34	4232	Diversion weir; 2.8 km canal; plus diversion weir; 3.9 km canal	
Te Arero Stm	3.55	81	2.4	10.5	10.59	4428	Diversion weir; 4.1 km canal	

Tauranga Taupo R headwaters	9.2	65	5.0	21.9	20.12	4042	Diversion weir; 350 m tunnel	
Tauranga Taupo R headwaters	10.7	65	5.8	25.4	23.64	4073	Diversion weir; 350 m tunnel	
Waipapa R Ranginui Rd	23.6	127	3.0	13.1	12.74	4262	Diversion weir; 2.8 km canal; 1.3 km pipeline	
Waipa R at Okahura Stm	10.6	102	9.0	39.4	47.81	5328	Diversion weir; 1.5 km tunnel	
Waipa R at Okahura Stm plus Tunawaea Stm	11.75	102	10.0	43.8	50.07	5010	Diversion weir; 1.5 km tunnel; plus diversion weir; 1.1 km pipeline	
Tunawaea Stm	1.3	243	2.7	11.8	13.28	4844	Diversion weir; 2.1 km canal; 2 km pipeline	
Waipa R	7.4	39	2.4	10.5	12.59	5267	Earth dam and penstock	
Tawarau R	6.3	76	4.0	17.5	15.76	3944	Diversion weir; 1.6 km canal; 100m pipeline	
Mohaka R below Wairere Falls	25.65	43	9.2	40.3	52.32	5683	Diversion weir below existing penstock; 4.5 km pipeline	
Mapiu Stm at Omaru Falls	2.4	105	2.1	9.2	8.37	3975	Diversion weir; 200m canal	
Mangawhio Stm.	2.7	136	3.2	14	19.54	6106	Diversion weir; 6.7 km pipeline	
Waihaha R West Taupo	11.2	105	9.8	42.9	36.34	3717	7m high weir; 1.15 km tunnel	
Marokopa Falls	6.75	119	6.7	29.3	17.99	2676	Diversion weir; 1.45 km pipeline	Economically attractive but with severe environmental constraints
Waikato R at Huka Falls	56.4	10	4.7	20.6	21.41	4556	650m pipe left bank	
Waikato R at Huka Falls	56.4	10	4.7	20.6	18.86	4005	300m canal right bank	
BAY OF PLENTY								
Rangitaiki at Kiorenui	23.7	44	8.5		25.65	3013	High dam	Some potential for cheaper diversion
Tarawera at Falls	11.7	73	7.0		21.15	3013	Low head	
Tarawera at Te Matae Road	11.6	103	10.0		36.12	3613	Medium head	
Kaituna at Okere Falls	24.3	26.5	5.2		19.28	3705	Okere Falls scheme	
Waimana at Matahi	20	55	9.0		36.32	4042	Diversion canal	
Tarawera at Fenton's Mill	13.8	55	6.2		33.13	5353	Low head	Environmentally sensitive
Mangorewa at Otamanariri	8.3	85	5.7		31.07	5451	Diversion canal	
Whatatane at Ruatohune	6.75	59	3.2		20.59	6357	Diversion canal	
Waiari at Te Matai Rd	3.9	93	2.9		21.15	7300	Diversion canal	

WEST POVERTY BAY								
Torere	20.9	39	6.8	29.8	33.24	4887	Earth dam storage	
Waitangi	37.3	10	3.1	13.8	21.26	6847	Earth dam	
Waitata	37.1	10	3.1	13.6	20.96	6761	Concrete arch dam	
EAST CAPE								
Waikohu	2.47	209	4.3	19	20.75	4801	23m earth dam at waterfall supplies tunnel to pwr stn.	
Waitahaia	8.87	96	7.1	31	49.18	6914	Diversion weir; 2.4km supply tunnel to power station	
TARANAKI								
Waiwhakaiho	4.7	72	2.8	12.2	46.78	4336		Augmentation of Mangorei Hydro Scheme
Patea	38.8	30	9.7	42.5	46.40	4869		Moderate level storage (higher scheme also unable)
Waitara	35	20	5.8	25.4	35.81	6173	Low level storage	
Waitara	48.2	10	4.1	17.7	27.68	6822	Low level storage	
Waitara	57.9	11	7.3	32	48.31	6596	Low level storage	
RANGITIKEI-WANGANUI								
Makotuku	13.74	89	10.2	41.5	34.12	3338	2-diversion weirs; 7-9 km canal	
Manganui-a-te-ao/ Mangaturuturu	3.92	240	7.9	42.9	27.99	3564	2-diversion weirs; pump station; 3.6 km canal & 3.2 km pipeline; inverted syphon; earth dam	
Hautapu at Turangarehe	4.97	227	9.4	41	33.74	3613		
Mangawhero			4.5		24.53	5444		
Makotuku/ Makara/ Mangaturuturu Orautoha	3.86	115	3.7	20.09	16.11	4287	Diversion weir; 4.9 km canal; 200m pipeline	Environmental constraints
Pohangina	6.82	167	9.5	41.48	34.50	3644	Diversion weir; 4.7 km pipeline	
Waimarino	6.61	107	5.9	24.4	19.22	3338	Diversion weir; 1.9 km canal	
Tokiahuru/ Mangaehuehu	16.64	62	8.6	36.7	35.65	4140	Diversion weir; 5.5 km canal	
Tokiahuru/ Mangawheraw hera			10.5	52.4	43.70	4177	Diversion weir; 41 km canal; pipeline; earth dam	
Makahikatoa			4.1		18.02	4373		
Waimiha	7.2	125	7.5	26.6	38.34	5114	Diversion weir; 4 km canal	
Ongarue	5.49	83	3.8	16.9	20.70	5524	Low dam; 2.9 km canal; 600m pipeline	

Mangatepopo/ Tawhitikuri	3.27	88	2.4	8.3	13.80	5714	Diversion weir; 2 km canal	
Whakapapanui / Makahikatoa	13.39	43	4.8	17	19.55	4066	Diversion weir; 2.4 km canal; 1 km pipeline	Environmental Constraints
Whakapapaitei/ Mangahua	7.24	53	3.2	7.9	18.02	5671	Diversion weir; 2.4 km canal	Environmental Constraints
Piopiotea / Makaretu	3.15	100	2.8	12.2	10.96	3913	2-diversion weirs; 3.5 km canal	
Mangawhoro	10.85	28	2.7	11.8	13.88	5230	Diversion weir; 2.5 km canal	
Makotuku / Makara /Makaraiti	2.45	115	2.5	10.9	9.31	3583	3-diversion weirs; 3.5 km canal; 200 m pipeline	
Tokiahuru / Mangaehuehu	15.8	62	8.6	36.7	35.64	4140	Diversion weir; 4.1 km canal/ pipeline	
Turakina / Mangapapa	7.66	47	3.2	14	19.33	6038	2-diversion weirs; 4.5 km canal	
<b>WAIROA</b>								
Cascade Falls/ Hopuruahine	4.64	93	3.6	15.8	15.67	3056	Concrete gravity dam	Environmental constraints
Omahanui/ Wakaretaheke	25.8	27	5.8	25.4	35.34	6081	Earth dam	
Waiau Gorge/ Waiau	21.9	45	8.2	35.9	53.00	6467	Gravity dam	
Tarapatiki/ Wakaretaheke	24.8	14	2.9	12.7	26.65	6828	Earth dam	
<b>HAWKES BAY</b>								
Tukituki below Folgers slip	12	40	4.0	14	18.09	4844	Diversion weir; 3.1 km canal/ pipeline	
Makaroro above Wakarara	7.75	65	4.2	19	20.34	4844	Diversion weir; 5.3 km canal/ pipeline	
Mangataura and Makaroro	13.46	41	4.6	20	26.48	5751	Diversion weir on Makaroro; 25m earth dam; 4.1 km canal & pipelines	
Waipunga Falls	6	80	4.0	17.5	15.82	3975	Diversion weir (2) 0.7 km pipeline	Environmental constraints
Tukituki At Rowes Rd.	62.6	18.5	10.3	45	67.83	6461	28m earth dam; adj. Power Station	
<b>DANNEVIRKE</b>								
Makuri / Gorge	6.3	100	5.6	25	32.72	5842		
Mangatainoka/ Lower Diversion	16.5	24	3.5	15	23.06	6590		
<b>HOROWHENUA</b>								
Mangaore Stream	11.34	48	4.5	21.9	19.60	4324	Diversion weir; 3.3 km canal/ pipeline	
Mangahao addition	4.29	257	9.2	40.3	34.93	6461	Maximum addition to Mangahao scheme	
Otaki/ Hautere	38.2	13.5	4.3	18.8	59.43	6786		

<b>WAIRARAPA</b>								
Kourarau Lower	0.78	133	0.9	4.76	1.22	1421	Runner lower steel penstocks	Extend potential of an existing station
Waingawa-Bend Cascade	14.8	43	5.3	23.2	20.54	3877	Earth dam; 12.75 km canal	
Waingawa-Kaituna	20.2	40	6.7	29.5	29.85	4422	Diversion weir; 4 km canal; headpond; 1.45 km pipeline; diversion from Mikimiko stream and Black creek	
Waiohine-West Bank Cascade	24.54	43	8.8	38.5	40.90	4654	Earth dam; low level gated spillway; 5 km canal	Cascade
Ruamahanga - Mt Bruce	12.8	60	6.4	28	35.65	5573	Earth dam; 3.2 km canal	
Ruamahanga - Reef Hill	12.3	43	4.4	19.3	26.22	5959	Earth dam; 1.6 km canal	
Tauherenikau & Taits Stream	10.75	38.5	3.5	15.1	21.53	6345	Earth dam; 2.3 km canal	
Cross Creek/Pakuratahi	3.08	253	6.5	28.5	43.93	6749	Earth dam; 1.13 km tunnel	
Ruamahanga - Stoney Flat	14.85	42	5.2	22.8	36.89	7092	Earth dam; 1.75 km canal	
<b>WELLINGTON/HUTT VALLEY</b>								
Upper Orongorongo proposed storage	1.36	265	3.0	13.2	2.43	808		
Whakatiki - Dam at Dude Ranch	7.13	74	4.4	19.2	19.00	4330		
Pakuratahi - Kaitoke Saddle	4.96	167	6.9	30.2	30.72	4458		
Pakaratahi - Railway vent shaft	3.43	105	3.0	13.1	14.15	4691		
Hutt - Totara Park	30	20	5.0	21.9	24.51	4912		
Akaturawa - Gillespies Road	8.45	35.5	4.8	21	25.23	5267		
Hutt - Forkes	6	50	3.5	15.5	25.68	7269		
<b>SCHEMES ASSOCIATED WITH ECNZ INSTALLATIONS</b>								
Moawhango Tunnel Outfall	12.5	27-19	4.5	21.6	6.31	1396	Replaces role of disperser valve	Simple and low risk
Mangahao R, No. 1 dam	8.1	33.5-22	3.0	13.8	6.63	2205	Replaces role of disperser valve	Limited civil works, simple proposal
Wairehu Canal	30	36.5	9.5	51.9	30.50	3209		
Mangaio Tunnel (drop shaft)	6	57	2.7	14	6.37	2352	Small flow, medium head, variable tailwater	Minor technical problems, dropshaft 1.219 m diam.
Leak sealing Lake Waikeremoana	Increased flow through Kaitawa	2 to 4129	Utilise existing plant; 4.0	35	guess 2.4	612	Repair to lake bend required, could be extended to other areas	Estimate of cost uncertain with very profitable gains
Waihohonu Stm including capture of Mangatoteonui	16.7	80	10.5	62.7	31.85	3031	Spring fed and has a regulated flow. A simple scheme.	Outside the boundary of the Tongario National Park
<b>OVERALL TOTAL</b>		<b>553 MW (&gt; 5 cents/kW)</b>				<b>CCI=3650 (Sept 1995)</b>		

Note: CCI is the Construction Cost Index of the Ministry of Works and Development

## South Island

Scheme, Site, River	Generation Flow (m <sup>3</sup> /sec)	Approx. Net Head (m)	Estimated Installed Capacity (MW)	Estimated Energy (GWh/y)	Capital Cost (\$ million)	Cost/kW (\$/kW)	Principal Features	Comments
<b>NELSON REGION</b>								
Boulder Lake Outfall	1.80	210	3.2	14.2	16.45	5075	100 m tunnel	Remote
Cobb Scheme Supplement	0.80	590		18.4	4.73		Headworks; diversion of existing scheme	ECNZ scheme supplement
Wangapeka River at Mt Jones	23.00	14	2.8	12.4	13.17	4640	Diversion weir; 2.4 km canal	
Fyfe River	2.80	270	6.4	28	23.37	3650	Diversion weir; 2 km tunnel	
Lake Matiri	12.00	80	8.2	35.9	20.65	2519	1.6 km pipeline	Seepage
Nardoo Ck	4.80	130	5.3	23.2	13.54	2556	Diversion weir; 1.8 km canal	Remote, environmental issues
<b>MARLBOROUGH</b>								
Pelorus River	22.00	40	7.3	31.97	32.25	4420	Dam	Flood flow uncertainty
Goulter River	6.50	45	2.4	10.51	11.41	4755	Diversion weir; 4 km canal	
Waihopai River	25.00	30	6.3	27.4	24.70	3952	Diversion weir; 9 km canal	Irrigation potential
Upper Awatere River	18.00	25	4.5	19.71	17.58	3905	Diversion weir; 3 km canal	
Conway River	13.00	40	4.3	18.83	17.37	4039	Diversion weir; 4 km canal	Flow not measured
Mangatini	2.36	157	3.3	14	11.95	3682	Diversion weir; pipeline	Acidic water, scenic area
Lake Rochfort	1.70	370	5.6	24	23.90	4264	2 diversion weirs, pipeline & canal	
Buckland Ck	1.79	245	3.9	17	14.54	3747	Diversion weir; 1.3 km pipeline	Environmental issues
Little Totara	2.43	125	2.7	12	14.86	5523	3 diversion weirs; 5.2 km pipeline and canal	
Awakiari River	2.14	105	2.0	9	11.95	5943	Diversion weir; 1.7 km pipeline	
<b>WEST COAST</b>								
Stony River (b)	7.30	110	6.7	29.3	20.28	3031	2 diversion weirs; 3.8 km canal	Alternative developments considered
Larry River (Awarau)	11.50	42	4.0	17.5	18.50	4621	Diversion weir; 4 km canal	
Giles (b) (with Stony flow)	8.00	45	3.0	13.1	17.38	5793	2 diversion weirs; 1.6 km canal	Alternative developments considered conflict with Stony (b)
Big River	7.10	60	3.5	15.3	18.12	5174	2 diversion weirs; 6.2 km canal	
Lake Christabel	6.10	125	6.4	28	33.89	5291	700 m tunnel; close underground outlet	Environmental issues

Upper Grey (a)	17.00	50	7.1	31	29.89	4211	Diversion weir; 1.6 km canal	
Amethyst River	2.50	400	8.0	35	27.64	3457	Diversion weir, 730 m tunnel	Access difficulties, small existing scheme not operational
Poerua River	22.40	50	9.4	41	46.29	4922	Diversion weir; 1 km tunnel	
L Wahapo	8.00	30	2.0	12	9.20	4599	400 m tunnel, replacing existing scheme	This scheme now constructed
Tartare River	4.00	180	5.9	31	32.18	5455	Diversion weir; 1.35 km tunnel	Access difficulties, small existing scheme not operational
Manakiaiu River	3.10	115	2.9	15	16.86	5813	Diversion weir; 700 m tunnel	Alternative development considered
Mahitahi River	15.80	70	9.0	47	29.89	3322	Diversion weir; 1.4 km canal	
Moeraki River	12.00	90	8.8	46	22.08	2508	Diversion weir; 2 km canal	
Zeilian Ck	4.00	270	8.8	50	30.79	3499	Diversion weir; 700 m tunnel	Not viable without Clarke scheme
Roaring Billy River	6.20	205	10.4	55	111.96	3454	Diversion weir; 900 m tunnel	Not viable without McFarlane scheme. Costs are for combined development.
Casey Ck	2.10	175	3.0	15	15.77	5257	Diversion weir; 170 m tunnel	Remote
Te Naihi River	12.30	95	9.5	50	50.58	5324	Diversion weir; 1.2 km tunnel	
<b>NORTH CANTERBURY</b>								
Boyle River	6.90	55	3.2	14	15.34	4788	Diversion weir; 1.6 km canal	
Kakapo Brook	3.25	180	5.0	21.9	15.92	3185	Diversion weir; 5.5 km canal	
Lake Sumner outlet (b)	32.00	30	8.0	35	36.00	4500	Low dam; 4 km canal	Alternative developments considered, environmental issues
Ashley Gorge dam	25.00	37	7.7	33.7	37.94	4927	37m earth dam	Recreation users
Ashley River	20.00	30	5.0	21.9	22.27	4453	Diversion weir; 5 km canal	Porous gravels
<b>CENTRAL CANTERBURY</b>								
Broken River	8.00	134	8.7	38.1	50.30	5780	Multiple sources; 2 powerhouses	
<b>SOUTH CANTERBURY</b>								
Jacks Stream	1.25	360	4.0	18	17.86	4465	Diversion weir; pipeline	
Boundary Stream	0.93	290	2.4	10.5	12.95	5395	Diversion weir; pipeline	
South Branch Ashburton River & Rangitata River: Opuha River	12.56	85	9.5	42	67.16	7069	Dam; 7 km canal	
<b>WAITAKI</b>								
Lower Waitaki Irrigation-								
McPhersons Rd 2	14.00	20	2.3	10.12	9.61	4126	Modifies existing irrigation races	



Waiareka-Kak anui Irrigation No 1	22.00	50	9.2	39.83	33.87	3692	Modifies proposed irrigation scheme	
Maerewhenua River	4.30	60	2.2	9.42	15.69	7297	Diversion weir; 10.5 km canal	
Ahuriri-Avon Burn No's 1 & 2	20.00	36.5	6.2	37.47	25.30	4081	Diversion weir; 2 powerhouses; 650 m tunnel	Environmental issues
Hopkins River	34.00	30	8.5	37.23	36.68	4315	Diversion weir; 5.5 km canal	
Huxley River	9.00	55	4.1	17.96	22.49	5482	Diversion weir; 4 km canal & pipeline	Isolated area, environmental issues
Temple Stream	6.00	60	3.0	13.14	13.14	4381	Diversion weir; 2.3 km canal & pipeline	
<b>DUNEDIN</b>								
Schemes in this report are not comparable with the other reports. They have therefore been omitted from this table and the report should be examined for details. All the schemes in this region have their water rights vested in the Dunedin City Council.								
<b>OTAGO</b>								
Taieri Falls	4.80	201	8.0	35	24.91	3114	40m earth dam; 900m pipeline	
Middle Taieri River No 1	18.00	45	6.8	29.56	26.62	3943	Diversion weir; 8.5 km canal	Alternative developments considered
Middle Taieri River No 2	18.00	20	3.0	13.14	15.42	5141	Part of a proposed irrigation scheme	
Deep Stream	4.20	194	6.8	29.78	27.46	4036	Diversion weir; 23 km canal	Dunedin City control water rights
Lee Stream	4.20	200	7.0	30.66	26.17	3740	Diversion weir; 8 km canal	
Catlins River	2.50	105	2.2	9.64	12.58	5716	Diversion weir; 11 km canal	
Manuherikia River	6.00	80	4.0	17.5	16.77	4192	Diversion weir; 7 km canal	
Manuherikia River Irrigation/ Hydro	9.00	90	6.8	22.7	13.83	2048	Uses proposed irrigation extension	Generation is irrigation dependent
Dunstan Creek	4.30	90	3.2	14	17.04	5324	Diversion weir; 8 km canal	
Beaumont River	1.40	180	2.1	9.2	10.69	5090	Diversion weir; 4 km canal	
Pomahaka River	25.00	30	6.3	27.59	25.00	3967	Diversion weir; 6.5 km canal	Recreational use
<b>OTAGO CENTRAL</b>								
Teviot River 'D'	5.10	86	3.9	17.1	8.60	2602		This scheme may be unavailable
Teviot River 'C'	6.52	100	5.8	25.4	9.48	2869		This scheme may be unavailable
Teviot River 'E'	3.50	90	2.8	12.3	9.83	2974	Uses existing Lake Onslow	This scheme may be unavailable
Wye Creek Renewal	1.33	320	3.8	16.6	8.08	2444	Diversion weir, replaces existing scheme	Work currently complete
Meg River Renewal	2.22	380	7.5	33	8.43	2551	Replacement of existing scheme, 2 powerhouses, storage dam	Work currently complete

Fraser River Upper	1.75	450	7.0	30.6	9.66	2924	8 m arch diversion dam, pipeline	This scheme may be unavailable
Thompsons Creek	1.70	165	2.5	11	10.48	3171		This scheme may be unavailable
Doolan Creek	1.48	190	2.5	11	10.50	3178		This scheme may be unavailable
Staircase Creek	1.10	480	4.7	20.6	10.74	3250	Diversion weir	This scheme may be unavailable
Luggate Creek	0.97	300	2.6	11.4	14.31	4329	Diversion weir	
Moke Creek/Lake Dispute	1.13	218	2.2	9.6	14.60	4418	Multiple sources using pumped water	
Dunstan Creek	3.47	81	2.5	10.9	15.03	4547		
Timaru River	3.75	72	2.4	10.5	20.15	6098	Diversion weir	
<b>SOUTHLAND</b>								
Mararoa Canal	17.50	39	5.6	24.5	24.33	4339	Diversion weir, canal	Recreation area
	OVERALL TOTAL		377 MW (>5 cents/kWh)			CCI=3650 (Sept 1995)		

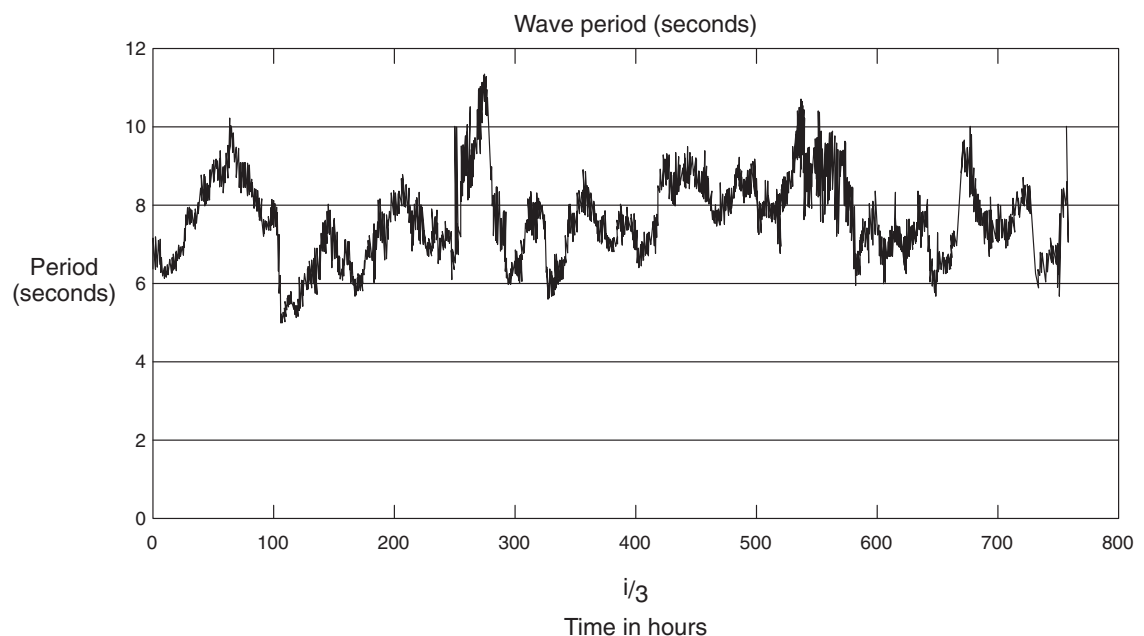
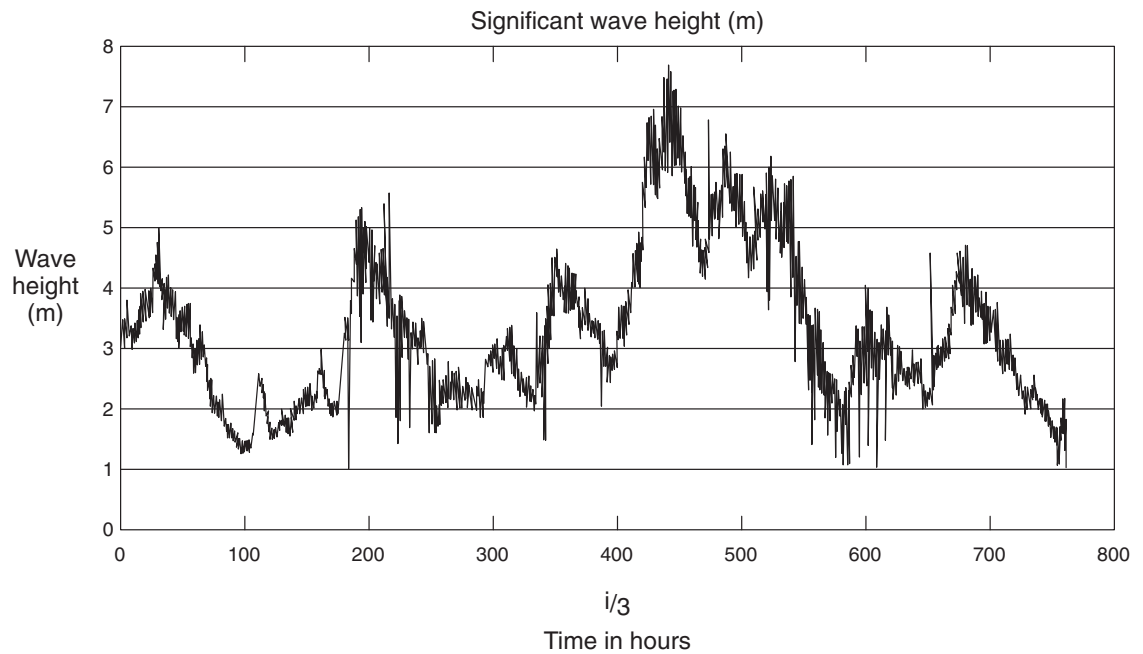
Note: CCI is the Construction Cost Index of the Ministry of Works and Development



## Annex 4.2: Wave Data Analysis Example

Wave height and period for April and November 1989 (averages over 20 minute intervals) for 760 hours of data.

Averages for two months: Mean wave height ( $H_s$ ) = 3.32 m Mean period ( $T_z$ ) = 7.58 sec



### **Power density — theoretical**

This is the theoretical calculation for the power in the waves. It is given in power per metre of wave front (kW/m). It generally gives an underestimate of the power, particularly if the wave pattern is made up of different frequencies, e.g. swell plus local wind effects.

$$\text{Density } p = 1000 \text{ kgm}^{-3} \quad \text{Power} = \frac{p(g)^2}{64\pi} (H_{s_i})^2 (T_{Z_i}) \quad g = 9.807 \text{ msec}^{-2}$$

This gives an average power of 48 kW / m

### **Power density — experimentally derived formula**

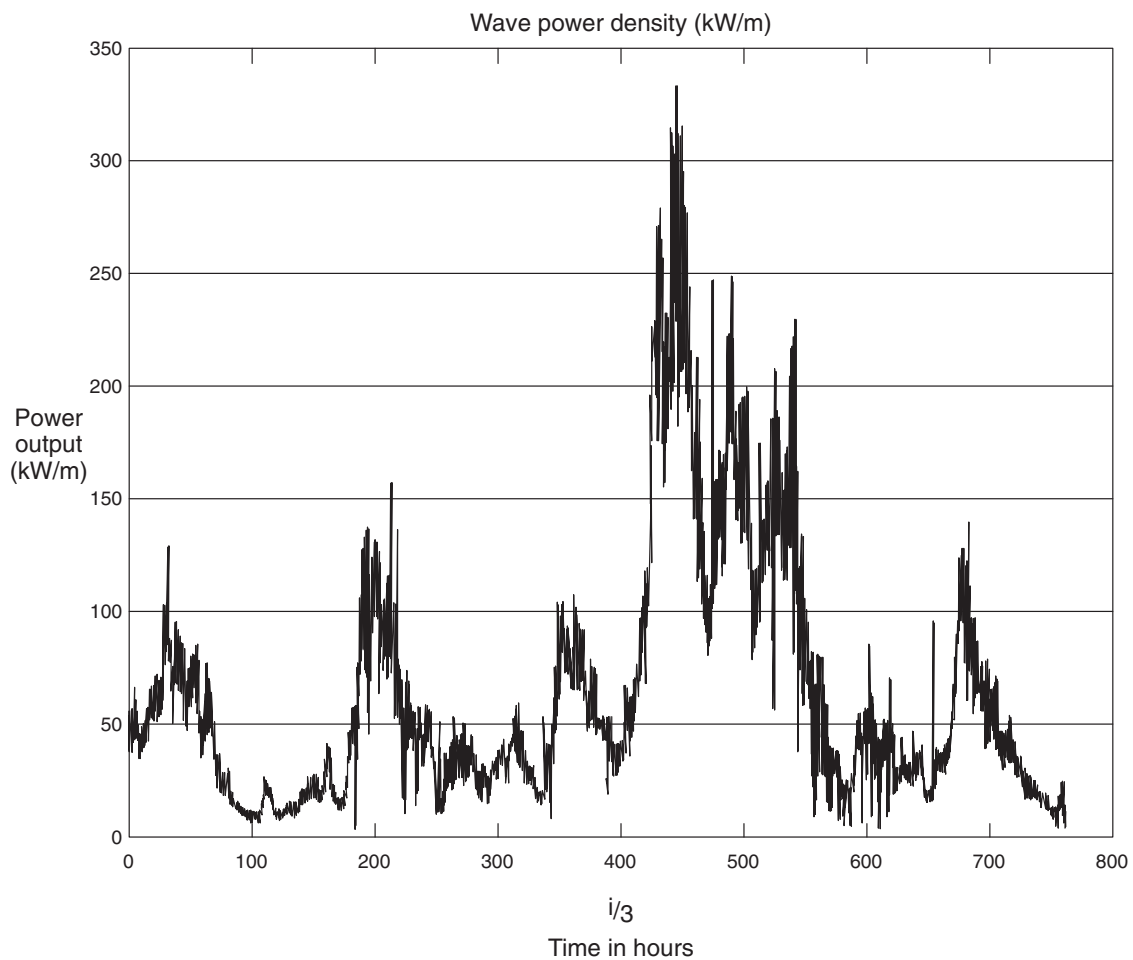
This is a more accurate formula, found from measurements at the Maui platform, where there is significant open sea swell.

$$\text{Power} = 0.625 \frac{\text{kW}}{\text{m}^3 \text{sec}} (H_{s_i})^2 (T_{Z_i})$$

This gives an average and maximum wave power for the period of:

$$\text{mean}(P) = 62.72 \text{ kW / m}$$

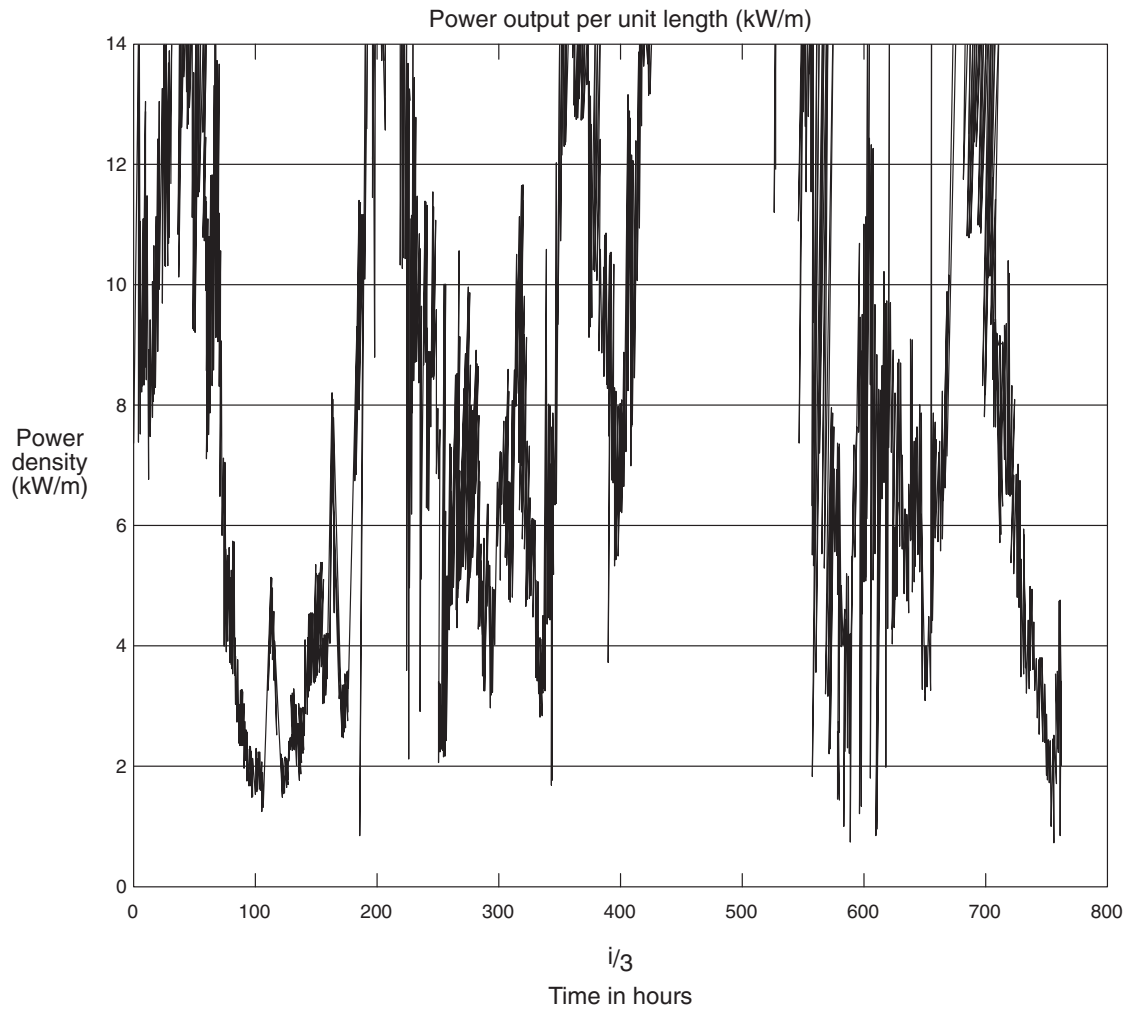
$$\text{max}(P) = 333 \text{ kW / m}$$



### **Actual power output**

The actual power output is typically 12% to 15% of the power in the waves, on an average basis, for wave power plants that have been built and tested to date. A wave power plant will have a practical limit to the power output, determined by the economic limit to generator size, cable size, etc. The power output is given per unit of collection length. The equation below uses an efficiency of 20% on an instantaneous basis, and a limit to power output of 15 kW. This gives an average efficiency of 15% (see below).

$$\text{Power output} \quad O_i = P_i \cdot 20\% \quad \text{limit} = 15 \text{ kW / m}$$



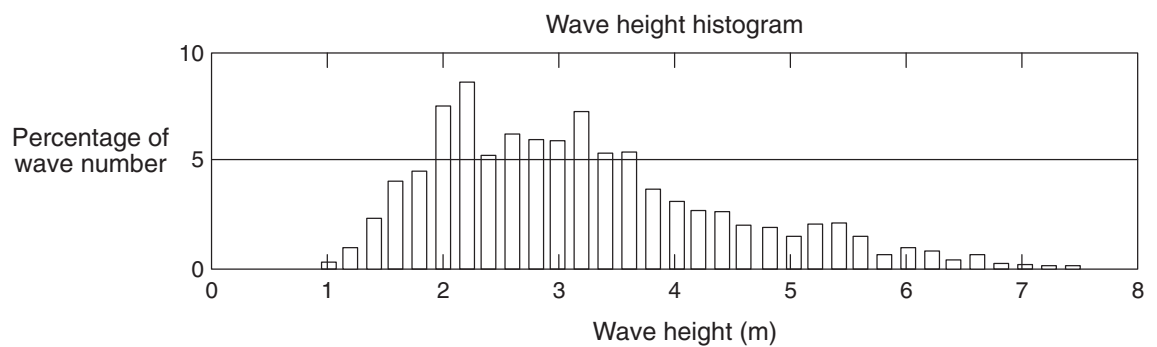
In this example the average power density output is:  $\text{mean}(0) = 9.2 \text{ kW / m}$

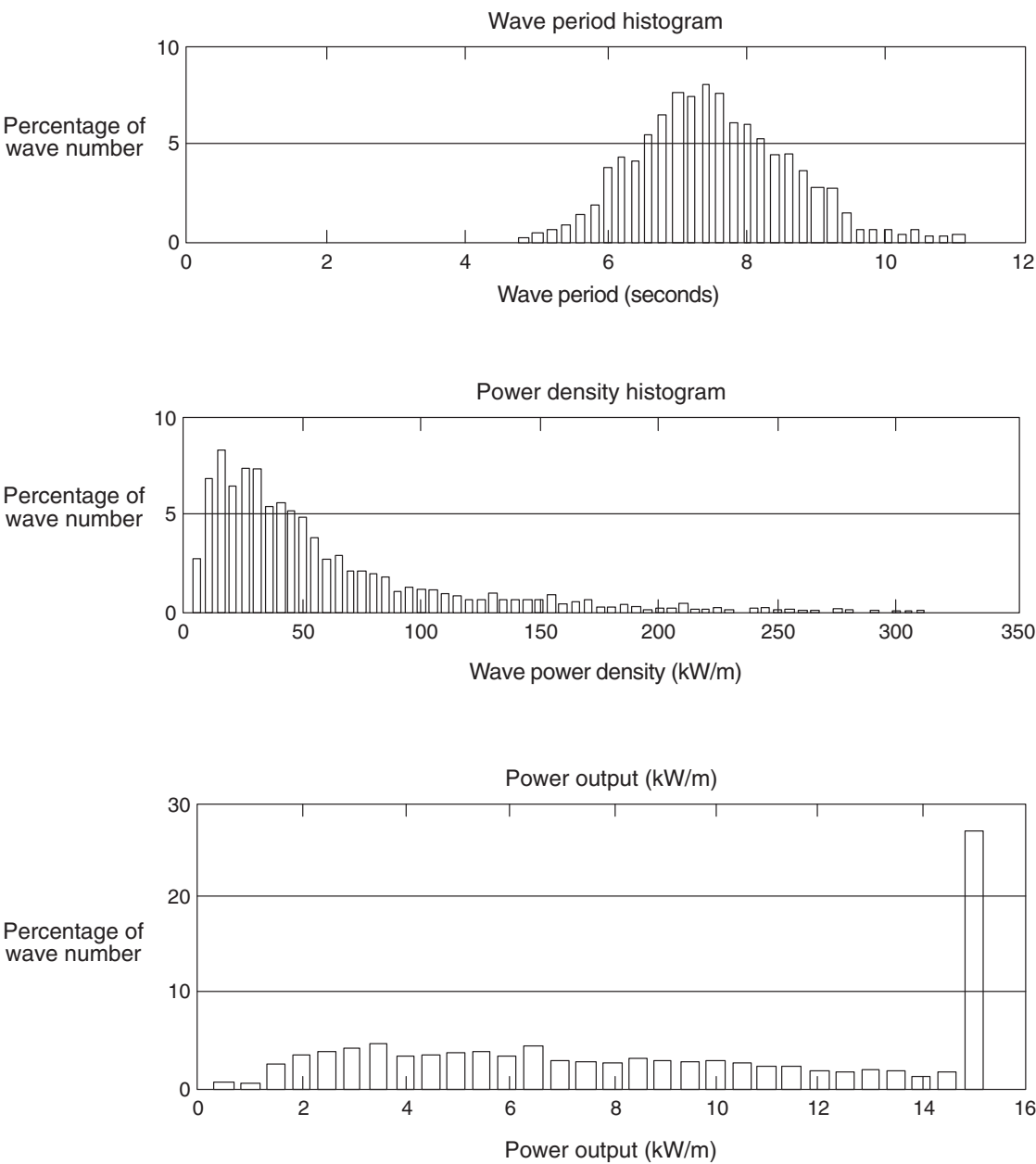
Hence the efficiency on an average basis is:  $\frac{\text{mean}(0)}{\text{mean}(P)} = \frac{9.2}{62.72} = 15\%$

This fits with quoted figures for real plant.

The capacity factor is:  $\frac{\text{mean}(0)}{\text{limit}} = \frac{9.2}{15} = 61\%$

### Histograms





**Weibull distribution**

This section calculates the Weibull distribution function that best fits the measured wave height distribution function. The fitted Weibull curve follows the same format (bin spacing) as the measured distribution.

$m_f$  = Measured distribution curve of significant wave height, taken from previous information

Number of samples in the data set =  $2.282 \times 10^3$

Defining of average and k-factor ranges (used to force the Weibull parameters within limits, increase accuracy and to reduce computational time)

$n = 10$

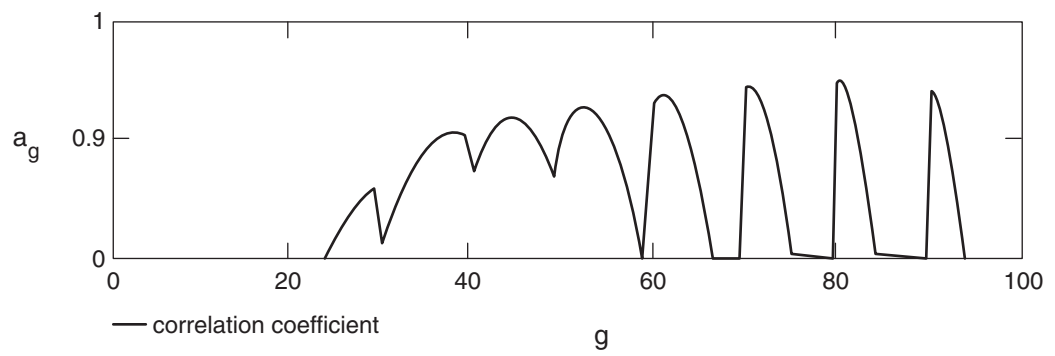
inputs  $V_{low} = 2.3$   $V_{high} = 4$   $V$  is the average and its allowable range is set here

inputs  $k_{low} = 1$   $k_{high} = 2$  The k-factor range is set here.

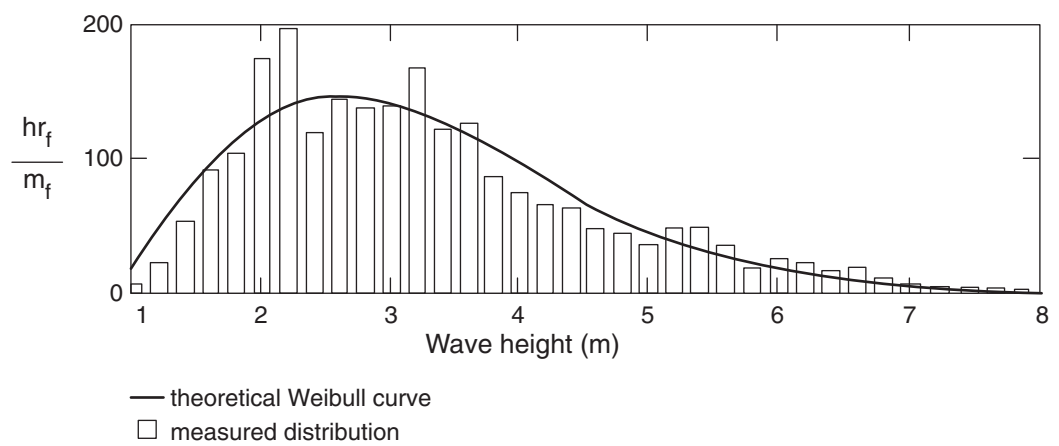
Correlation analysis fitting the best curve to the actual data



Correlation matching variable  $a_g$



$\max(a) = 0.947795 = \text{maximum correlation coefficient}$



Results of calculation (estimated Weibull model)

Average wave height = 3.3 m

Weibull k-factor (consistency) = 1.889 m



# 5 *Wind Power Generation*

Wind farms have become relatively common in Europe and the USA in recent years. The reasons why the first large wind turbine generator was only built recently (1993) in New Zealand, are the relatively cheap power price and, ironically, the risk that the nature of the local wind resource may not suit current wind turbine designs causing premature component fatigue. The ECNZ turbine operating in Brooklyn, Wellington, is demonstrating that this may not in fact be the case.

The principles of harnessing the wind to generate electricity are well understood and also relate to small turbines, many of which are already successfully operating in New Zealand.

This report focuses on large wind turbine generators (>200 kW) that are connected to a utility network and are installed on land rather than offshore.

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## 5.1 Technology Review

### 5.1.1 Introduction

Wind is caused by atmospheric temperature and pressure gradients. It can be utilised in a variety of ways to provide electrical and mechanical power.

The power available in the wind varies according to the wind speed raised to the third power. Small increments in wind speed can therefore significantly alter the resource potential.

Energy production depends on the shape of the annual wind speed distribution curve, combined with the control and power generating characteristics of the wind turbine generator (WTG).

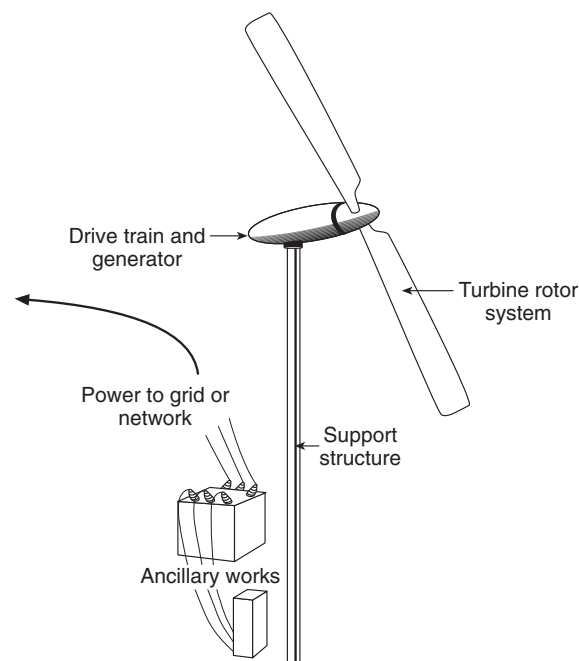
WTGs can produce alternating current (AC) or direct current (DC) electricity as required by the application, e.g. DC for small remote power systems or AC for grid connections.

They can be located on land, or at sea with towers fixed to the seabed or on pontoons. Normally at sea the wind is stronger, more consistent, and less turbulent, however capital costs are greater.

This document focuses on WTGs that are connected to a utility network and which are installed on land.

### 5.1.2 System elements and scale

The main elements of a wind turbine generator are the turbine rotor system, the drive train, generator, and support structure together with the ancillary works (see Figure 5.1).



**Figure 5.1: Main elements of a wind turbine generator**

#### *Wind turbine rotor system*

The rotor system consists of blades attached to a hub with associated blade control mechanisms on many designs. Two configurations are possible (see Figure 5.2):

- 1) the vertical axis wind turbine (VAWT), where the blades move around a vertical line, perpendicular to the wind direction; and
- 2) the horizontal axis wind turbine (HAWT) with one, two or three blades, and the horizontal axis in line with the wind. This is the predominant design of commercially available turbines.

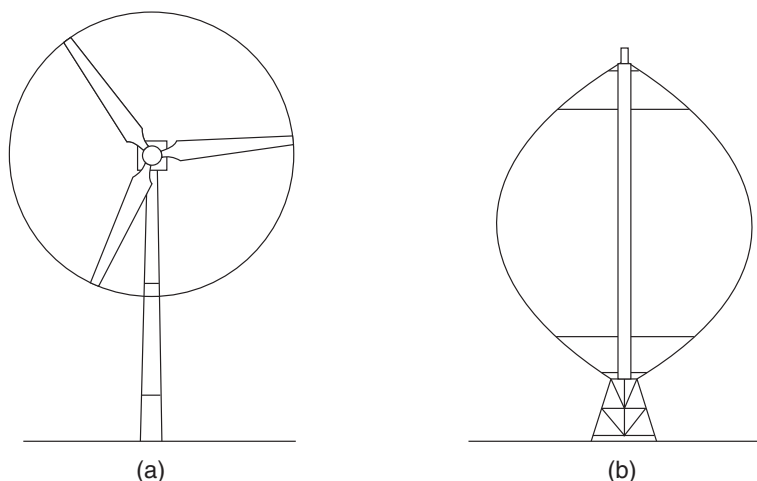


### *Support structure*

A typical HAWT grid connected machine stands 30 to 40 metres tall at hub height with blades of radius 12 to 20 m. The tower supports a nacelle which houses the drive train, generator and mechanical controls. Towers are normally constructed from tubular steel, concrete, or steel lattice. The bottom of steel tubular towers can accommodate electrical control and switchgear equipment.

### *Drive chain and generator*

The rotor hub is connected to an electrical generator through a drive train. Most drive trains include a gearbox, however direct drive generators are becoming more common for larger WTGs.



**Figure 5.2: Examples of typical HAWT (a) and VAWT (b) wind turbines**

### *Ancillary works*

These include control cubicles and buildings, power distribution lines, transformers, substations, maintenance facilities and access roads.

Commercially available WTG's installed today are proving to be durable and efficient, and are cost effective and financially competitive with other forms of electricity generation in many parts of the world. These turbines are the building modules for wind farms.

About 95% of the turbines installed today are of the three bladed design. The blades are rigidly mounted to the main shaft, which is horizontal. The rotor is coupled to an induction generator through a speed up gearbox. The average size wind turbine installed last year in Europe was approximately 400 kW. The seven German turbines at the 3.5 MW Wairarapa wind farm are 500 kW each.

During the last two decades of WTG development there has been a rapid improvement in reliability and an increase in capacity. Only a few years ago the average size of commercially available WTGs was around 250 kW. At present 1000 kW units are commercially available and 1.5 MW WTGs being tested by manufacturers are expected to become commercially available in 1996-1997.

The WTG converts the available energy in the wind into useable utility grade electricity. It is designed to extract as much energy as possible out of the wind, up to the so-called rated wind speed. At the rated wind speed (for most turbines around 12 to 14 m/s) it produces its nominal or rated power. Between the rated wind speed and the cut-out wind speed (for most turbines being between 25 to 35 m/s), the WTG control system limits the output power to an average of approximately the nominal output rating. Within this operating window, the WTG "spills" energy in the form of excess wind.

The two main control mechanisms used to keep the output power more or less constant are pitch and stall control, both being aerodynamic control systems. The pitch control system uses an electronic feedback control mechanism while the stall control uses the inherent aerodynamic characteristics of the airfoil (passive control system). Both systems and certain technology derivatives are used in the WTG industry.

### 5.1.3 Calculation of annual generated energy

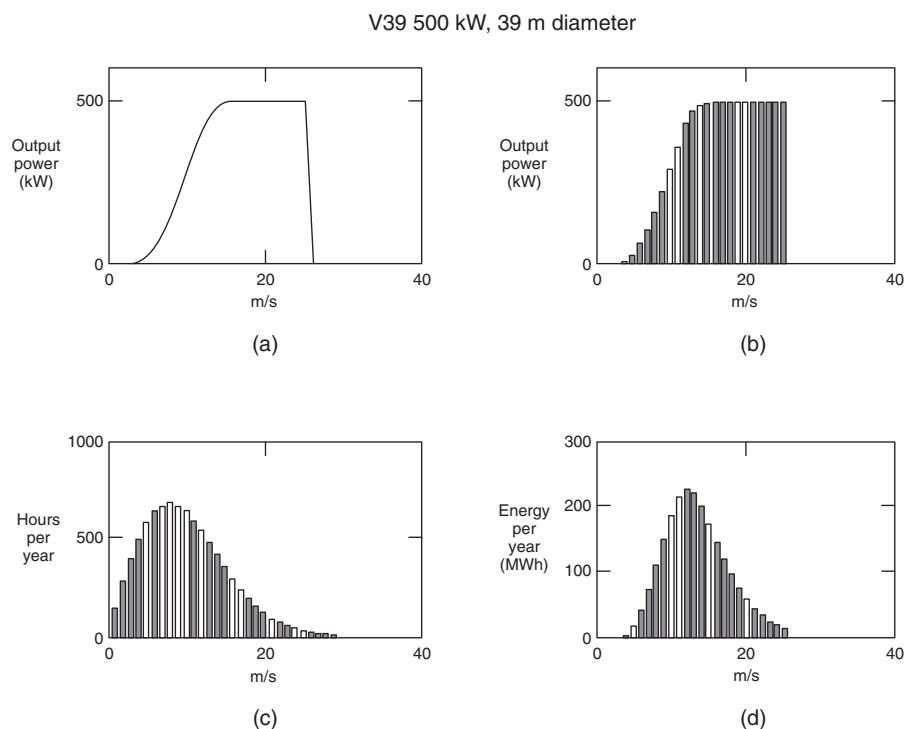
The following example quantifies the amount of energy that a particular WTG can generate per year. The amount of energy produced by a WTG at a particular site depends on the wind speed distribution curve for the investigated site and the WTG control and power generation characteristics.

The long term wind speed distribution curve as measured on a specific site is ideally used in these calculations based on actual measurements and cross correlation techniques. Where this information is not available, then theoretical Weibull distribution curves can be used. A Weibull statistical distribution curve is used in the example in Figure 5.3 for a site with an annual wind speed of 10 m/s and a shape factor constant of 2.

To perform the calculations, it is easiest to translate the wind speed distribution curve into a histogram showing the number of hours per year that the wind speed is within each wind speed interval (or bin), for example the wind speed between ( $x$ ) and ( $x+1.0$ ) m/s. The power curve of a WTG describes the power output of the turbine as a function of the wind speed. This curve is also translated into a histogram (Figure 5.3b).

The number of hours that the wind speed is within a particular wind speed interval (or bin) is then multiplied by the corresponding WTG power output. This is repeated for each wind speed interval. The sum of these multiplications yields the annual electricity generated by the WTG (in kWh) for that particular site. This calculation assumes that the WTG is available 100% of the time, which is not the case in practice due to maintenance periods, etc.

Errors are introduced with this methodology in regards to the uncertain behaviour of the WTG around the cut-out wind speed. There is evidence that “hysteresis” losses due to shutdown near the cut-out wind speed can be substantial. To include those losses a more complicated analysis needs to be undertaken. The example shown in Figure 5.3 is based on a 500 kW WTG with 39 m diameter blades installed at a 10 m/s average wind speed site.



The total power generated per annum is  $2.215 \times 10^6$  kWh/year per WTG

Figure 5.3: Calculating the annual energy production

### 5.1.4 Types of systems and application

Wind power can be used to directly power machinery, as in history where wind mills have been used to pump water and grind grain. More recently, wind turbines are used to generate bulk utility grade electricity, generate

power for remote villages (village electrification), or produce end products such as ice, hydrogen, desalinated water etc.

New Zealand has opportunities for hybrid wind/diesel projects. These consist of one or more WTGs combined with a diesel generator to provide continuous electricity, and can be installed on many of New Zealand's islands or at the end of long distribution lines with small loads.

The most common application of wind power is WTGs with an installed capacity ranging from 200 to 600 kW supplying utility grade electricity to power companies. These WTGs are usually arranged in wind farms — multiple wind turbines forming a single managed unit in a generally contiguous area. The modular nature of WTGs means wind farm capacities can be variable to suit land availability, load demand and other factors. Generally wind farms have a capacity of up to 100 MW. Medium size WTGs are probably best suited to New Zealand conditions due to the high mean annual wind speeds, but this is yet to be proven.

This document is written with a focus on the bulk electrical energy production from large and small wind farms.

### **5.1.5 Technical Status**

Wind power technology is a mature technology and many commercial plants are operating overseas. However, there has not been enough experience with modern plant to fully prove energy output, operation and maintenance (O&M) costs, plant lifetime and some other life cycle issues, particularly under New Zealand conditions where the average site wind speed can be as high as 10 m/s on some of the best sites in New Zealand. A lot can be learned from the US and Europe experience, however there is no equivalent high wind speed site there with a long record available regarding the above issues. It can be argued that Wellington's WTG is the only WTG installed in a 10 m/s site which is actively researched and this has only been operating for three years.

O&M costs, as for most machines, tend to increase throughout the life of a WTG. The overall life expectancy is unclear; 15 to 25 years with, possibly, a major overhaul every 10 years is often assumed.

Wind power R&D started with both very large- and small-sized machines ranging from 3 MW to 1 kW capacity. Design then converged to intermediate sizes. Height and power output are now increasing to take advantage of better wind conditions at higher elevation and economies of scale. This trend is helped by a better understanding of fatigue and other material stress issues to which larger machines were earlier prone.

WTGs designed 15 to 20 years ago were optimised to extract as much energy from the wind as possible without consideration of fatigue. It was only more recently that fatigue issues received appropriate considerations. Fatigue R&D now constitutes a large amount of WTG R&D effort.

Unlike hydro power plants, the inflow of wind energy harnessed by a WTG is turbulent, chaotic, unsteady, varies with elevation (wind shear), and changes direction continuously. Modern WTGs have to deal with this time and space variable energy inflow which together with the 100 million plus revolutions of a rotor during its life, makes fatigue of a WTG an important issue.

There are three approaches regarding fatigue issues and how to extend the life of a WTG:

- 1) Design and build a WTG as strongly as possible so that it can deal with the large number of stress cycles and stress amplitudes. This usually results in the 3-bladed, rigid hub, fixed speed, horizontal axis design.
- 2) Design and build a WTG to be as flexible as possible so that the stress amplitudes are reduced (but not the number of cycles). This results in flexible one or two bladed designs.
- 3) Use a rigid design but with variable speed, which gives some of the benefits of flexibility as above.

The number and magnitude of stress cycles is predominantly affected by the number of hours that the WTG is in operation, the operational rpm of the WTG, and the wind spectrum of turbulence and gust cycles. The last two decades have seen many different designs evaluated, resulting in a rapid rise in experience for designers.

New, advanced WTG designs are likely to use one or more of the following technologies:

- variable speed rotors (with power electronics) to extract up to 15% more energy with less power output variation;
- variable speed rotors to reduce fatigue loads in the rotor and drive train;
- direct drive to avoid needing a gearbox;
- advanced airfoil designs;
- advanced materials for blades and other components;
- power electronics;
- diffuser technology;
- flexible components; and
- hybrid controls.

The Commission of European Communities is actively supporting R&D and demonstration projects to improve WTG reliability, efficiency and economics as well as to improve resource assessment and analysis.

The majority of WTG manufacturers are investigating variable speed machines, using power electronics to supply a constant alternating voltage and frequency to the grid. These machines usually use DC generators and their speed can vary over a range between 18 to 42 rpm. Several manufacturers are investigating the possibility of eliminating the gearbox from the drive train by using low speed electrical generators.

Advanced technologies such as flexbeam rotors and teetering hubs have been developed to reduce the stress amplitude cycles. However the cost effectiveness of these methods have not been proven and some teetering machine designs have been changed back to rigid hubs to save costs. Research is also being undertaken on stall-controlled WTGs and specially designed stalling airfoils.

Due to the nature of New Zealand winds, most towers installed will be of the tubular design which have fewer maintenance requirements than lattice towers, increased safety for maintenance personnel, reduced engineering risk and less risk to bird life since research shows that lattice towers cause higher bird fatality than tubular towers. A wide variety of tower designs have been developed to deal with different ground conditions, material availability and preference for various capital and O&M cost splits. Steel tubular and concrete towers require higher capital, whereas lightweight guyed towers have higher O&M costs. Tower design also takes into account wildlife considerations.

Foundations vary from massive concrete deadweights for poor ground conditions such as peat, to little more than grouted bolts on solid rock sites.

### **5.1.6 Application and integration limits**

Backup power supplies and satisfactory integration with the national grid are the key issues which are common to all power stations. Wind power is not continuous so it cannot be relied upon solely unless there is an energy storage system such as hydrogen production for fuel cell generation or pumped hydro using storage lakes. Wind power is well suited to work with other sources that can cover any wind shortfall, and can be integrated, within limits, with a national grid system.

Grid systems dominated by thermal power generation will limit wind power penetration. The cost of significant spinning reserve (thermal turbines ready to instantly provide power) erodes any benefits wind power offers. The hydro domination of New Zealand's grid means this is less of an issue as hydro can be quickly activated. There is a synergy between wind and hydro power. Hydro dams could be seen as providing storage for wind energy and when wind energy is available hydro storage is maintained. Wind energy could, therefore, increase New Zealand's hydro storage capacity if a coherent control strategy was to be adopted.

It is noted that none of these potential problems of grid integration will occur during the early stages of wind power in New Zealand. The first wind farms will be small in comparison to the total New Zealand system. Predictions show a possible total installed wind power capacity of 50 to 100 MW by the year 1998-1999, which will be only 1% of New Zealand's total generating capacity.

Present wind turbine installations in New Zealand are limited to a number of small scale, mainly private producers, usually in regions such as Great Barrier Island where mains power is not available (see section 6.2). However, now that the potential for wind power has been realised, several developers are studying the feasibility of large scale wind generation. New Zealand has several possible sites throughout the country (see section 5.2) identified as being able to supply several hundred megawatts each. Even though there are theoretical limits to the penetration of wind power into the existing electricity system, these limits are at present academic. It is estimated that more than 30% of current electrical energy demand could be met by wind power. This would mean that about 2000 MW would need to be installed, but this is unlikely in the near future. In the future, due to technological advances particularly in the field of power electronics, a greater capacity could be installed on some sites. All the electricity load growth could therefore be met from wind power and the potential resource is huge. The main limit is economic. As cost of electricity increases and WTG prices decrease, lower wind speed and more remote sites will become economic.

It is interesting to note that, of all the WTGs presently installed worldwide, about 98% use induction generators to convert the kinetic energy from the wind into electrical energy. Utilisation of synchronous generators would increase the acceptable level of grid penetration, but would cause dynamic instabilities in a WTG if no drive train compliance was built into the unit. Future generation variable speed WTGs with power electronics could have, theoretically, a 100% grid penetration.

### **5.1.7 Critical factors**

The critical factors to wind power development in the near future include installation costs, the amount of wind resource available close to load centres and uncertainty over O&M cost and WTG life.

The capital cost of the WTG is usually around 50% to 70% of the total wind farm development cost, and it will be hard to reduce in the short term. Hence it is important to find sites with a high average wind speed, with low turbulence levels, which are easily accessible and which have a nearby electrical infrastructure that is appropriate for the load. For example, Wairarapa Electricity has upgraded the nearby existing 11 kV line for their 3.5 MW wind farm near Martinborough to 33 kV in order to reduce transmission losses.

Energy outputs are very sensitive to average wind speeds. A 10% error in the wind speed estimate means a 30% change in output. Site selection based on careful measurement is therefore crucial.

The wind speed required for a viable development depends on the life cycle costs compared with alternative electricity supply costs. In Europe, a site with a mean annual wind speed of only 6.5 m/s is viable, whereas cheaper power generation costs in New Zealand, based on existing hydro schemes, means that only those sites with high mean annual wind speeds above 10 m/s will be economic. This entails locating development at the high wind sites that have few environmental issues to address and that are close to major load centres. The Wairarapa Electricity wind farm was the first to come on-line and planning consent has been granted to the Tararua wind farm proposal for a site overlooking Palmerston North.

There is an upper limit for selecting a site set by the maximum wind speed that the WTGs must be able to survive. This is associated with the average site wind speed, which, as a guideline, should not be higher than 12 m/s.

## **5.2 The Current New Zealand Wind Energy Resource and Potential**

New Zealand has a wind power resource capable of meeting future growth in electricity demand. Specific site resource information is largely inadequate to confirm the supply cost/quantity relationships necessary for most of this potential. Applying engineering judgement to the data that does exist indicates that New Zealand could obtain electrical power from the wind equivalent to at least 30% of present day consumption at costs of less than 16 c/kWh, and that several hundred megawatts could be installed for 7 to 10 c/kWh.

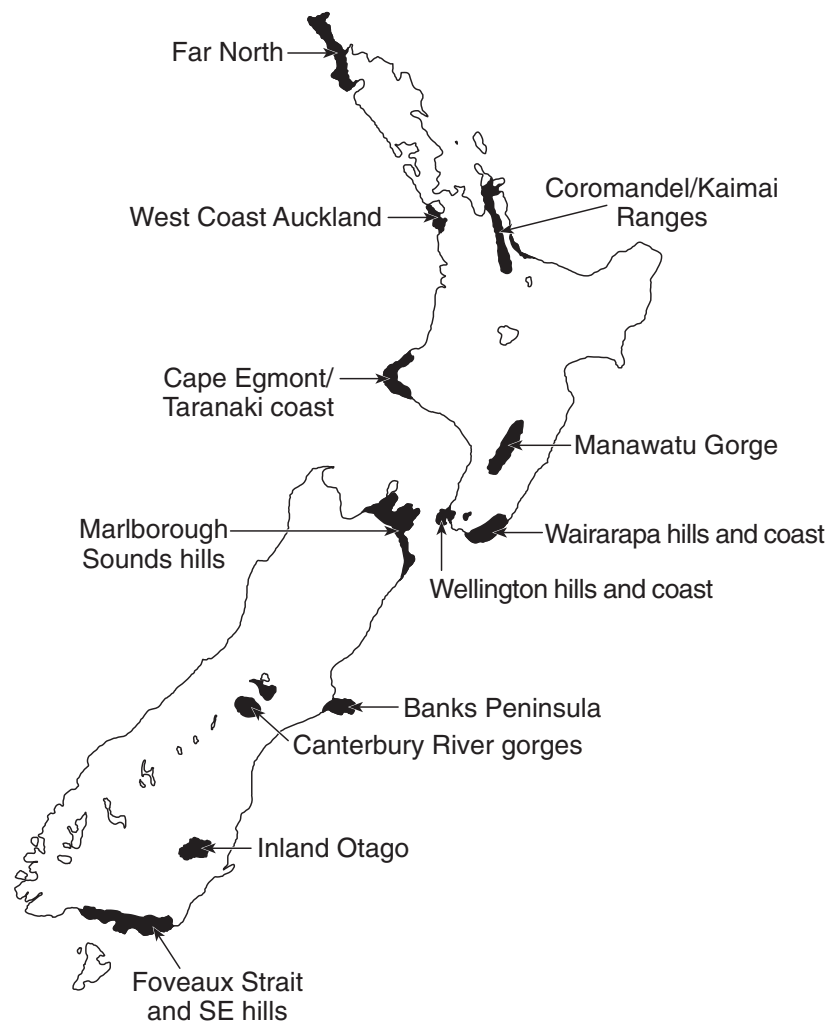
An assessment of the wind energy resource in Otago (NZERDC, 1979), indicated the magnitude of the resource. Development in almost half the region was excluded on environmental grounds. If 10% of the remaining land was developed as wind farms with a conservative capacity factor of 20%, the estimated annual power output would be 8000 GWh, which is about 36% of the current annual consumption of 32,000 GWh.

Extrapolating the Otago results to the whole country and assuming that around 5% of the land is suitable for wind farms, leads to an estimated annual wind power potential of over 50,000 GWh (rising to nearly 100,000 GWh if a capacity factor of 35% is adopted). The Otago study did not subdivide the region's wind potential into supply cost classes. It is not possible to accurately estimate how much of the potential 50,000 GWh will fall into different supply cost classes using existing information, although an attempt was made in a recent Renewable Energy Report (Ministry of Commerce, 1993).

### 5.2.1 Location of resources

New Zealand is well suited to wind power development since it lies across the prevailing north westerly winds. It also has a long coastline, where, due to sea breezes and lack of interference, winds tend to be strongest. Most regions of New Zealand have a wind resource that could be practically developed, although not all have a resource that is economic at present.

An early study (NZERDC, 1987) identified 16 potential wind farm areas all over New Zealand, of which 4 were then discounted. While this study had a number of limitations, it forms the basis of the supply curve estimates in this report. The 12 areas considered suitable for wind farms are shown in Figure 5.4.



**Figure 5.4: Location of potential wind farms**

Constructing wind farms close to load centres avoids electrical losses incurred in the transportation of the energy through the national grid. It is estimated that the losses in the existing New Zealand electrical system are about 10%. Embedded generation projects are important to reduce these losses. Besides the waste of energy, this has several important secondary effects. Population statistics for New Zealand urban areas



provide a good indication as to which windy locations are likely to be developed first. The main population centres are shown in Table 5.1.

Comparing these locations with the isovent map (Figure 5.5) shows why the first developments are taking place near Palmerston North and Wellington where there is a high wind resource as well as a high load.

The large majority of load centres are near the coast. Since coastal winds are generally higher than many inland winds, other than on the ranges (Figure 5.5), future wind farms may well be situated in the coastal environment, subject to planning consents based on the New Zealand Coastal Policy statement.

Whangarei	coastal environment
Auckland	coastal environment
Hamilton	inland
Tauranga	coastal environment
Rotorua	inland
Gisborne	coastal environment
Napier/Hastings	coastal environment
New Plymouth	coastal environment
Wanganui	coastal environment
Palmerston North	inland
Wellington	coastal environment
Nelson	coastal environment
Christchurch	coastal environment
Dunedin	coastal environment
Invercargill	coastal environment

**Table 5.1: Main population centres of New Zealand**

### **5.2.2 Potential supply and variability**

Table 5.2 lists several possible wind farm regions, and their estimated annual energy productions. Although the energy output is high, it was assumed that, using present-day technology, grid penetration will not be allowed to exceed 15% to 20% of the total grid capacity to ensure reliable operation of the electricity network. Even so, the wind power potential equates to an installed capacity of almost three times that of the Clyde Dam.

Conservative energy calculations used to derive Table 5.2 were based on the following assumptions:

- Twelve of the 16 originally identified areas were included due to anticipated problems with obtaining planning consent at the other four.
- Three percent of the available identified land area would be used for wind farm development. Available land is the land which is left over when cities, forests, parks etc., are excluded from the areas shown in Figure 5.4, and 3% usability was a conservative, professional estimate based on possible problems which might occur for the remaining 97% of land during planning consent applications.

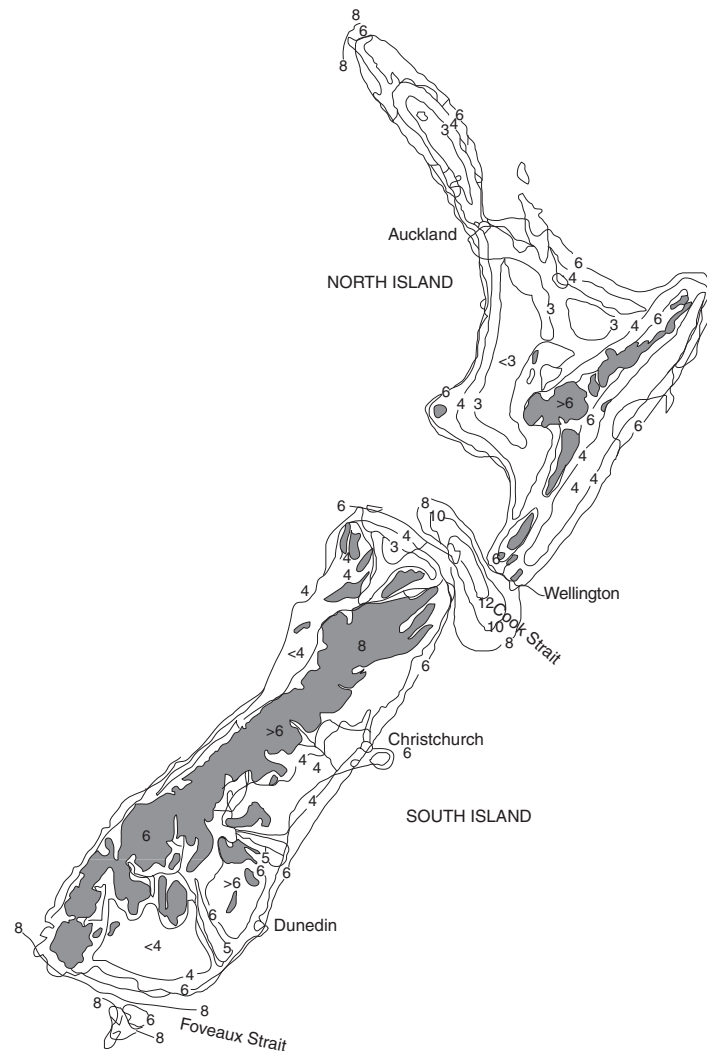
Objections to a planning application can be based on telecommunication interference, audible noise, visual impact and various other reasons. It is possible that the actual useable land is larger than 3%, which would increase the amount of energy captured proportionally.

- WTGs are spaced inside a wind farm, 3 rotor diameters apart within a row with the rows spaced 7 rotor diameters apart, which is acceptable if the wind comes from a predominant wind direction for more than 50% of the time. This level of spacing is necessary to avoid unnecessary fatigue damage due to wake turbulence effects from upstream WTGs. For a 40 m rotor diameter, each turbine would need three to four hectares of land.

The wind speeds in Table 5.2 were derived from New Zealand isovent maps which show the average annual wind speed at 10 m above ground level. Together with the Weibull distribution and appropriate shape factors, this data was combined to construct wind speed frequency distribution curves which yields the number of



hours per year that the wind blows within certain wind speed ranges. This combined with a WTG power curve as shown in Figure 5.3 resulted in the stated annual energy productions for each site assuming the WTGs were available 100% of the time. In reality, an availability percentage should be taken into account which gives the percentage of time that the WTGs are available to produce power above the cut-in wind speed. Non-availability is caused by scheduled and unscheduled maintenance, and can also include a slight reduction in output due to wake effects and related losses.



**Figure 5.5: Isovent map of annual average windspeeds at 10 m above ground level**

A 92% availability was used to derive the data in Table 5.2. A higher percentage availability has been observed in many European wind farms where the average wind speed is lower than in New Zealand. At those sites, maintenance can be scheduled in no wind periods, so that the availability is not reduced. However in the higher wind speed sites in New Zealand it is usually necessary to do maintenance on the machines during windy periods which will reduce the turbine's availability.

An extensive study of the dynamic loads on wind turbines in four European wind farms (Joule, 1993; White, 1996) identified the effects of wake turbulence on neighbouring turbines. The wake loading caused increased fatigue on the downstream turbines even when a distance away of five times the rotor diameter.

As a result, design guidelines were produced and a methodology developed for characterising the design turbulence intensity for a WTG in a wind farm situation on both simple and complex terrains. The combined effect of site topography and wake flow on turbulence is not yet understood, but does impact on wind turbine loads to a considerable degree.

Potential Wind Farm Sites	Wind Speed (m/s)	Energy produced per site (GWh/year)
Far North	7.4	1,074
West Coast Auckland	7.2	393
Coromandel/Kaimai Ranges	8.8	1,507
Cape Egmont/Taranaki coast	8.4	866
Manawatu Gorge	10.5	1,945
Wellington hills and coast	10	223
Wairarapa hills and coast	8.7	1,152
Marlborough Sounds hills	7.8	1,064
Banks Peninsula	8	461
Canterbury River Gorges	6.4	518
Inland Otago	6.4	1,284
Foveaux Strait and SE hills	8	2,171
<b>Total energy in GWh/year</b>		<b>12,656</b>

**Table 5.2: Potential wind farm sites and annual power outputs**

The project also identified that, particularly in higher wind speed sites, developers would be wise to:

- obtain a detailed description of the wind resource over a long period, since extreme gusts, turbulence intensity and variations in mean wind speeds over the site may exceed the standard wind turbine design calculations;
- if long-term wind records are not available, correlate short-term data with a nearby reference weather station in order to predict not only electricity production levels, but the extreme gust wind speeds; and
- tune the standard turbine configuration to specific site conditions assuming the wind regime data is well documented. To optimise a WTG's performance could entail altering the control algorithm or the set angle of the blades, though care must be taken to maintain any manufacturer's warranty.

In New Zealand, the speakers at a technical workshop on wind turbulence effects (EECA, 1994) confirmed that, although a windy country, the wind is not more gusty than elsewhere and the turbulent intensity is only average by international standards. However, premature fatigue of turbine components could result from the larger number of fatigue cycles within a given time period resulting from the higher wind speeds.

### 5.2.3 Variability of the resource

Annual wind patterns vary by around 10% (whereas rain patterns vary by around 20%). The variation can, to some extent, be forecast and therefore calculated and allowed for in the resource assessment. Seasonal variation patterns are consistent with annual variations. Thus, the annual resource for a particular site can be accurately predicted and can be used to forecast energy generation in New Zealand as a whole.

Wind power is often mistakenly taken to be a fluctuating power source which will have a detrimental effect on the reliable supply of high quality electricity. To understand the impact of wind power on the reliable operation of New Zealand's electricity network requires evaluation of five possible problems:

- lack of replacement generation during calm periods;
- power fluctuations due to wind farm operation;
- system voltage fluctuations due to wind farm operation;
- harmonic disturbances due to wind farm operation; and
- network failure.

Analysis of each of these issues reveals that overall:

- the voltage fluctuations of WTGs are small;
- a smoothing effect on the power output from wind farms occurs in proportion to the number of WTGs; and
- it is possible to forecast the daily power output of a wind farm and thus take advanced action to ensure the reliable delivery of energy to the consumers. However, a Consumer analysis of MetService forecasts presented by the media showed that wind direction forecasts were only correct 58% of the time. Wind strength forecasts were not analysed (Consumer, 1996).

#### **5.2.4 Power fluctuations**

Power fluctuations of a single WTG, by the minute, second or split-second, are a function of the variability of the wind speed as well as the technical characteristics of the WTG.

The nature of wind power is such that any single WTG has a fluctuating power output. In a wind farm this variation decreases dramatically with an increase in the numbers of units installed.

The total power output of several WTGs in a wind farm will show, under ideal conditions, a drop in the output power variance as an inverse of the number of WTGs installed. Thus the greater the number of turbines in a wind farm, the larger the smoothing effect is on the power output of that wind farm.

The majority of future New Zealand wind farms will be smaller than 50 MW and will be spread around the country. This will enable the existing electricity network to take timely action and ramp up or down additional capacity as the wind farm outputs change.

A grid-connected wind farm operator should be able to forecast cut-outs due to high wind speed probability and forewarn network operators. Shutting down parts of the wind farm in a controlled manner to facilitate the smooth transition from wind power to conventional power generation should be possible. High wind speed shutdown situations are likely to occur only a few times per year, depending on the site characteristics, but are the most problematic in regard to the power output variability because of the fast transition between full load and no load conditions. Several manufacturers are addressing this issue and it is expected that this problem will be solved in the near future.

The hourly and daily variations in wind speed are easily accommodated by the forecasting of the wind resource and scheduling the power generation of other generating plants. A similar smoothing effect occurs on the grid over a longer time frame if several wind farms are installed at different geographical locations throughout New Zealand.

The forecasting of wind speeds at particular wind farm sites for a time period of 15 minutes in the future can be achieved with a reliability of  $\pm 10\%$ . The forecasting of tomorrow's weather can be reasonably accurate although the forecasting wind speed windows will be broadly described as "strong winds" or "moderate winds". These can be translated to expected amounts of wind energy to enable the expected spinning reserve capacity and alternative generation sources to be adjusted accordingly.

Daily wind speeds are influenced mainly by the movement of weather systems, however deterministic diurnal effects also play a role. Wind speeds are sometimes significantly higher in the afternoon than at other times of day, this diurnal pattern being more marked at lower altitudes. Diurnal wind patterns may be variable but system power planners can often use them to advantage. There are consistent seasonal variations in New Zealand winds, but overall the monthly and year-to-year variations are small.

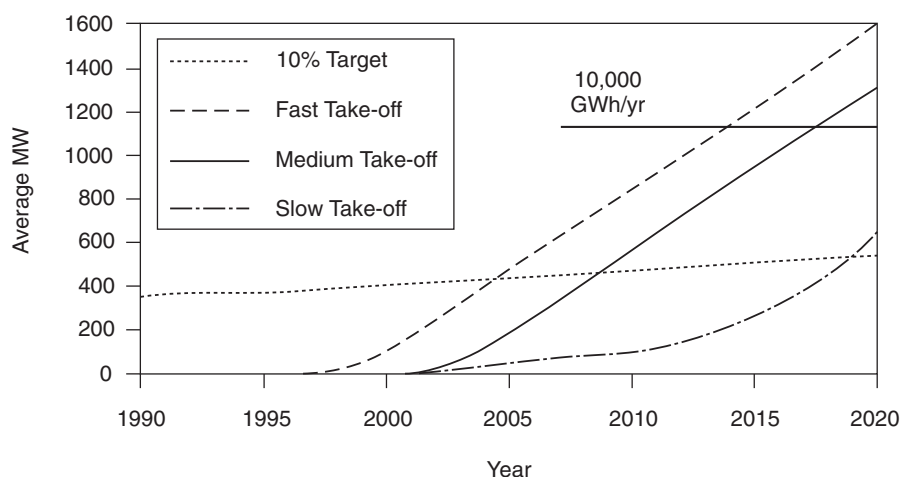
#### **5.2.5 Present utilisation of the resource**

Several units <10 kW have been installed by individuals, mainly in remote areas, and a single 225 kW unit, installed by ECNZ in Wellington, has been operating successfully for the past three years.

The 3.5 MW wind farm development by Wairarapa Electricity consisting of seven, 500 kW Enercon turbines manufactured in Germany, has been generating since early June, 1996. In addition, planning consents were

granted for a 60 MW site on the Tararua ranges, this being a joint project between Central Power and Merrill International, but a final decision to proceed is pending.

Thus, progress to date has gone from small turbines only in the early 1990s, to 225 kW in 1992, to 3.5 MW in 1996, with the prospect for at least 60 MW in 1997. To what degree such rapid growth can continue cannot be predicted with any accuracy, but a range of scenarios, compared with a target level of 10% of total electricity demand being met by the wind is given in Figure 5.6 (Henderson, 1996).



**Figure 5.6: Growth prospects for wind power in New Zealand depending on the rate of take-up and compared with a target to generate 10% of the total power demand from wind**

### 5.3 Environmental and Social Aspects

The list of environmental benefits of wind power generation compared with other forms of energy supply is extensive:

- Wind farms can be installed in a modular fashion thus optimising land use versus load demand. The modularity is also important for projects developed on sites which can accommodate a larger installed capacity than that necessary for embedded generation. Such projects can be extended at a later stage when transmitting the energy beyond the embedded load becomes economic.
- Wind farms can be installed on small areas of land and so can be sited close to load centres thus reducing the need for additional or upgraded transmission lines.
- The construction period of wind farms is short. Construction disturbances to the environment or local communities are thus for a shorter period. The 3.5 MW Hau Nui wind farm took Wairarapa Electricity only eight weeks to complete the roading, foundations and electrical distribution network upgrade, with a further six weeks to erect the turbines and undertake final commissioning.
- Wind power does not produce greenhouse gases and there are no hazardous by-products. The resource is free and limitless in supply. It is noted that for every kilowatt hour of electricity generated by wind rather than coal, the emission of one kilogram of the greenhouse gas CO<sub>2</sub> is prevented. The energy used in the manufacture and transport of a WTG is recovered after a few months of operation.
- Wind power, along with other renewables, will help New Zealand's goal of reducing CO<sub>2</sub> levels.
- Any visual or noise impact of a wind farm is only present during the life of the project. WTGs can be removed without leaving major scars on the landscape, a depleted resource or a damaged environment. Traditional means of generation, such as hydro or gas, do not have this feature, though other renewables, such as solar, do.
- Only 1% of the land on which a wind farm is built is actually taken up by the turbines. The remaining 99% can continue to be used for farming activities.

- There is a correlation between wind power generation and load demand. The wind tends to blow more strongly in the afternoon when electricity demand is high. Higher winds generally occur in spring when storage lake levels for hydro generation in the South Island are at their lowest and loads are high. Also strong winds often are associated with cold weather and hence larger heating loads. This therefore reduces transmission costs and thermal generation.
- WTGs provide a tangible visualisation of electricity actually being produced. Making electricity generation visual for people in this way can encourage efficiency and general awareness.

Listed below are a number of relevant issues when comparing wind power with other forms of energy supply.

- The price of wind power is constantly improving. From 1976 to 1989 the cost of generating electricity by wind dropped by 60 to 80 cents/kWh. It is currently around 7-14 cents/kWh, depending on a site's average wind speed and on operation and maintenance costs in New Zealand conditions. It is already economic at the highest wind speed sites.
- Wind power will make the country's electricity supply more secure by increasing the diversity of energy sources. The variability of wind power from year to year is less than the variability of hydro power, which means that wind generation can help reduce the threat of future power crises due to unforeseen meteorological events.
- Wind power fits in particularly well with New Zealand's hydro storage systems. The existing lakes behind the hydro dams act as a store of power. Water can be saved while the wind is blowing, and can then be used when the wind speed temporarily decreases.
- Wind farms can be installed to generate electricity relatively close to the population centres they supply. Known as embedded generation, this reduces transmission losses and permits local ownership and control.

### 5.3.1 Environmental concerns

As with any power generation technology, careful consideration must be given to what effect it will have on the environment. The most common concerns are:

- visual impact;
- noise pollution;
- effects on wildlife; and
- interference to radar and radio/TV/communication traffic.

These issues need to be addressed at the early stages of project development, particularly with regard to the Resource Management Act. Other issues raised in the Resource Management Act will need to be addressed as well.

The **visual impact** of a development is the most contested subject at planning hearings. Opinions about the visual impact of a proposed wind farm differ greatly and are often influenced by other issues. Opinions also change regarding the visual impact. Often the acceptance decreases after a development plan has been unveiled. However, it is noted in several overseas studies that the acceptability increased again and at times surpassed the original acceptability level once the development was operational. Several studies revealed that perceived negative opinions regarding visual and acoustic issues can change drastically after opponents have had the opportunity to visit an actual wind farm.

**Noise** emissions can be calculated and measured. New Zealand Standard NZS 6802 (Assessment of Environmental Sound) and New Zealand Provisional Standard DZ 6808, specifically for WTGs, give guidance and recommendation regarding the treatment of industrial and wind farm noise. Following these guidelines is likely to result in a thorough assessment for the resource consent process.

**Bird strike** has been closely monitored overseas and does not seem to be a major issue away from main migration routes. It may be partly species dependent, in which case only monitoring of wind turbine on New Zealand sites will determine if the problem is significant.

The **interference** with telecommunications can be calculated and can therefore be minimised by careful layout of a wind farm. Near field considerations need to be taken into account as well as microwave corridors (based on first Fresnel zones). The reflective properties and the emission of electrical noise of a WTG and the complete wind farm need to be investigated on a case by case basis. However, WTGs have been located close to telecommunication sites without causing any problems (Figure 5.7). The Wairarapa Electricity wind farm has been built on the site of an existing microwave telecommunication tower with no apparent adverse effects to date.



**Figure 5.7: Wind farm surrounding a telecommunication site in the USA**

Any development will make an impact on the natural environment and it is of importance to weigh up the benefits and the disbenefits of a wind farm project as well as compare them with other forms of power generation.

Embedded generation is the first practical application of wind power in New Zealand as in the Wairarapa. Since many load centres are on the coast, it is expected that the demand for future generation wind farms will also be on or near the coast. This has already created a problem for the resource consent application made by Energy Direct for a wind farm on Baring Head in Wellington. It was declined on the grounds that it was not an appropriate use of this coastal environment. This could have a major influence on the development of coastal wind farms in the future, since precedent is often used in courts and planning tribunals. The decision is under appeal.

An indication of public concerns relating to wind farm developments is provided in the proceedings of a seminar on “Wind Farming in New Zealand, Potential and Prospects” (Massey University, 1992). Although held several years ago, the report of the discussion session to which the public were invited outlines the perceptions which will remain until operational wind farms prove otherwise. These concerns and other environmental issues are also covered in the report *Guidelines for Renewable Energy Developments – Wind Energy*, EECA, 1995.

## **5.4 Economics**

An outline of the information needed to evaluate the economics of a wind power project is given in Figure 5.8.

### **5.4.1 Capital costs**

Typical capital costs for purchasing and installing wind turbines in the immediate future are expected to be in the order of:

- NZ\$2,000 to \$2,300 per installed kW



- NZ\$900 to \$1,450 per square metre of wind swept area by the rotor.

Cost reductions of up to 30% for the WTG can be expected within a few years due to increased manufacturing capabilities. This will translate to an overall cost reduction to possibly as low as \$1,600 per installed kW.

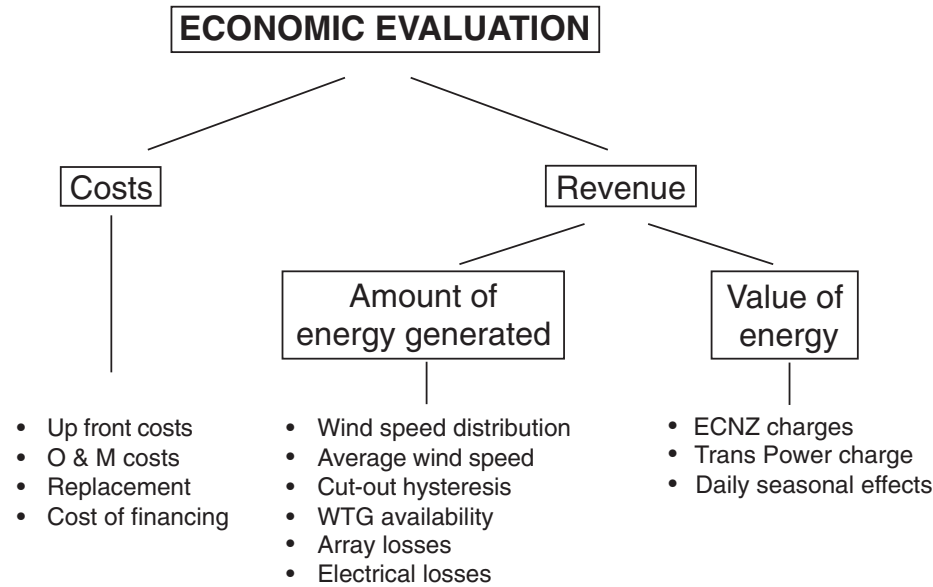


Figure 5.8: Economic analysis of wind farming

**5.4.2 Energy output**

The amount of energy that can be generated per annum depends on several parameters (Figure 5.8). The amount of power available in the wind is proportional to the cube of the wind speed and the swept area of the rotor. Calculations to obtain energy output predictions are based on the wind speed distribution curve for the site in question, the power curve of the WTG, and the assumed availability of the WTG for generating. Large variations in annual energy production predictions are often noted when comparing calculations using theoretical WTG power curves as provided by manufacturers with measured outputs or independent guaranteed power curves. Variations of 20% or more between theoretical and actual energy outputs have been observed in the industry, which has a direct influence on the economics. This problem relates to small turbines of 1 to 2 kW as well as to larger machines.

The amount of electricity generated per year is related to the swept area of the rotor (Figure 5.9). This is based on the traditional energy calculation methodology described earlier and can be used to verify manufacturer's claims.

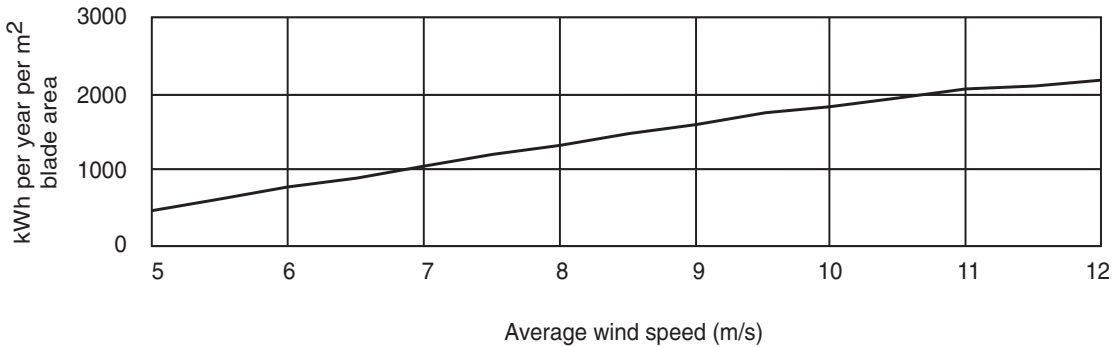


Figure 5.9: Electricity per square metre of rotor



### 5.4.3 Operation and maintenance

These costs are difficult to estimate without experience of operation under local conditions. The O&M costs in American wind farms are often estimated as an annual 2.5% of the capital cost. Several wind farm estimates in Europe have split the operational and maintenance costs into 2.5% of capital cost for the annual operation and 1.3% to 1.5% for the annual maintenance cost. The wind farm size in Europe is generally smaller than in the USA, where the wind farms have hundreds of machines. In the cost example presented in this section, 2.5% of the capital cost was allowed for annual O&M costs.

### 5.4.4 Internal rate of return

The estimated cost of wind energy in terms of c/kWh is only one economic indicator used by developers. The internal rate of return (IRR) of an investment being another.

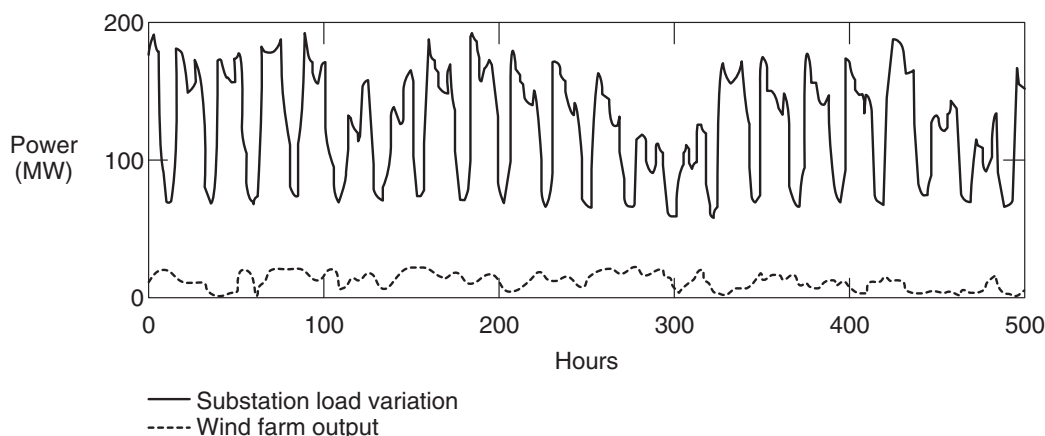
The IRR is calculated using the capital cost and O&M costs in combination with the assumed project revenue based on the amount of electricity that a wind farm produces and the value of the electricity. The major difference between energy cost calculations and IRR calculations is the value of the electricity.

This value is the price that is paid to not only generate the electricity but to deliver it. Price is thus a combination of the energy cost (how much it would cost to buy the electricity from another generator such as ECNZ or Contact Energy), plus the transmission costs through the Trans Power network. The prices of electricity in New Zealand are based on charges from ECNZ/Contact Energy and Trans Power. The combined average cost is at present around 7 c/kWh.

The ECNZ energy charge is built up from several different components:

- the hedge prices;
- a New Zealand location factor;
- a security charge; and
- transmission related charges.

The prices are dependent on the time of day and the season so it is not possible to simply equate average ECNZ charges to the average consumption price or the average wind generation value since these also depend on diurnal and seasonal wind patterns. The variability of load compared with the variability of a wind farm output is shown in Figure 5.10. Note the difference between the local demand for five working days and two weekend days. The wind farm output ranges from zero to a peak output of around 18 MW. The load varies from around 70 to 190 MW.



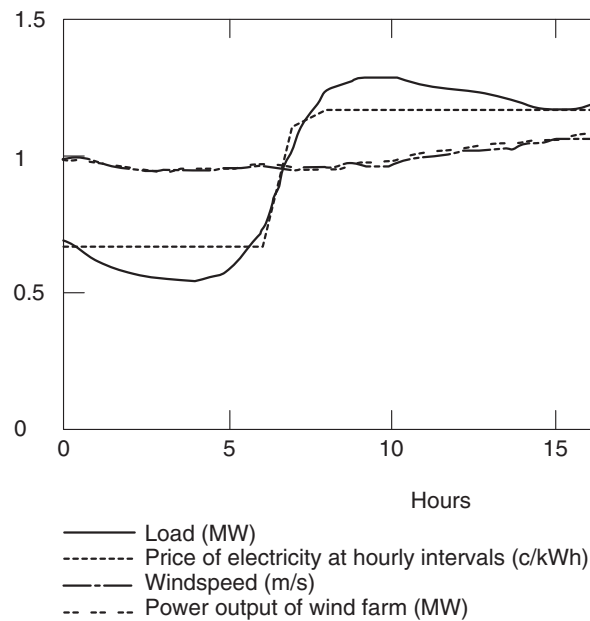
**Figure 5.10: Time traces of typical load and wind farm outputs**

For simplicity it can be said that the ECNZ component of the total electricity charge is about 70%, or 4.5 to 5 cents per kWh of the total electricity cost. A more detailed ECNZ pricing structure is shown in Figure 5.11.

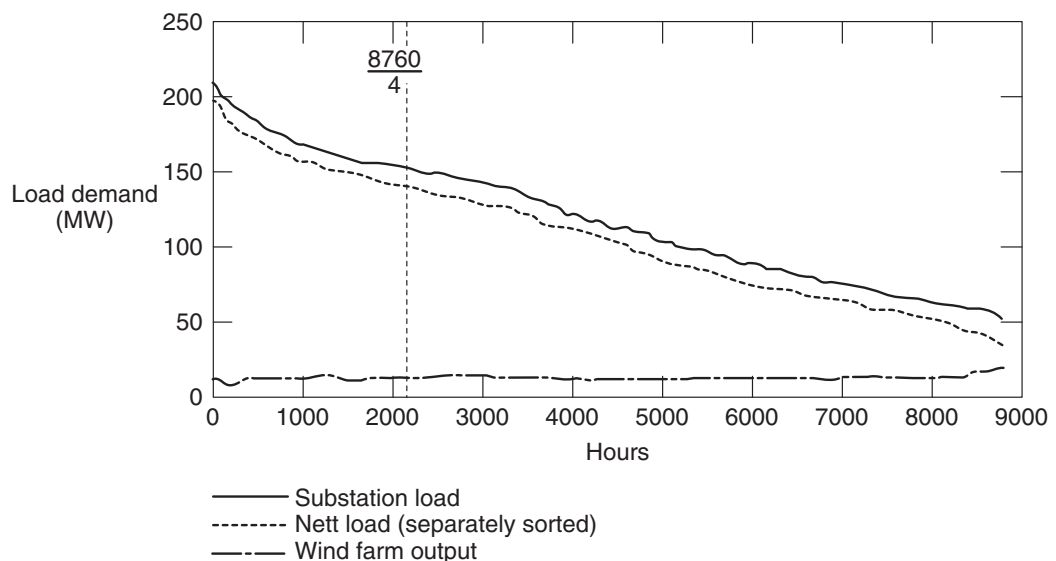
The Trans Power charges at present are based on Trans Power assets and in simple terms equate to about 30%

of the total energy charge or about 2 to 2.2 c/kWh. However it is a simplification to equate the Trans Power charges to a per kWh value. If electricity is generated by a power utility company, then it avoids the ECNZ energy charge but still has to pay the fixed Trans Power charges. This means that the value of wind generated electricity per unit is equal to the ECNZ energy unit charge (4.5 - 5 c/kWh) only, which makes it difficult for wind generation projects to compete, whether embedded or not.

Industry sources anticipate the proposed Trans Power charging regime will be based on a maximum demand charge in combination with a kWh charge based on the upper quartile of load demands throughout a year. Figures 5.12 and 5.13 show the total load demand profile for each load level at a typical substation throughout a 12 month period, sorted into descending order of power demand. The nett load is the substation load less the wind farm output at the corresponding time, and this is also sorted into descending order. Also shown is the difference between these two curves which is the load demand met from the wind farm.



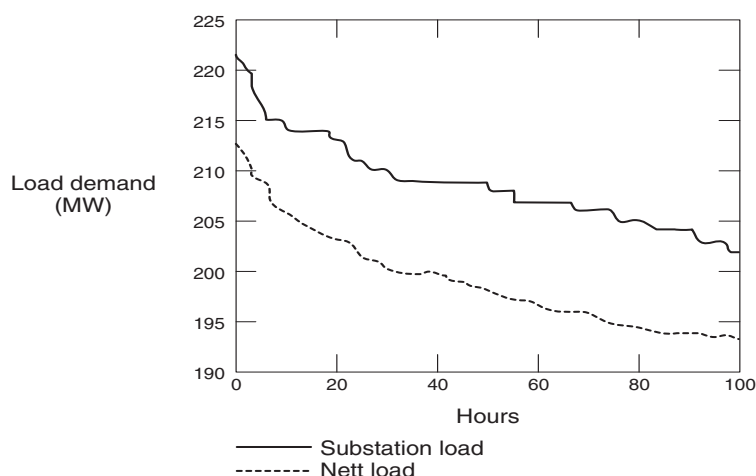
**Figure 5.11: Normalised diurnal hedge price in relation to typical daily load demand with typical wind speed and wind power variations superimposed**



**Figure 5.12: Annual load duration curves for grid power and wind farm output of 18 MW capacity**

Analysis, based on site specific available wind and load information in combination with WTG power curves, has shown that, typically, 50% to 65% of the Trans Power charges can be avoided. Therefore, the present value of electricity (or total avoided charges) for embedded generation equals approximately 6 to 6.5 c/kWh. The avoided Trans Power cost is an untested concept, but it is believed to be reasonable to equate the worth of electricity to about 6.25 c/kWh for wind energy for embedded projects.

A further complication in regard to calculating the worth of electricity is that the IRR is calculated over the lifetime of the project. In taking normal inflation into account, it is expected that electricity costs will inflate above general inflation. Anticipated electricity price inflation values of 2% to 4% have been quoted in the industry but with possibly the next two to three years having no increase above normal inflation levels.



**Figure 5.13: Detailed hours of maximum load demand from the first 100 hours shown in Figure 5.12**

#### 5.4.5 Other economic studies

The following example is based on a wind power cost study recently performed by the Ministry of Commerce (Biggar, 1995). It was based on a 12 MW wind farm installed for \$2,000 per kW at a 10 m/s site giving a generation of 2.4 GWh/year for each 600 kW turbine. A 12 MW wind farm with twenty 600 kW turbines would cost \$27m and would generate 48 GWh/year.

Biggar (1995) calculated the cost of electricity to be around 7 c/kWh based on several assumptions regarding the cost of the WTG and the amount of energy that can be produced. A more refined analysis would probably not show a markedly different cost. The analysis is supported by the cost of 7 to 9 c/kWh quoted by Henderson (1996) for a wind site at 10 m/s.

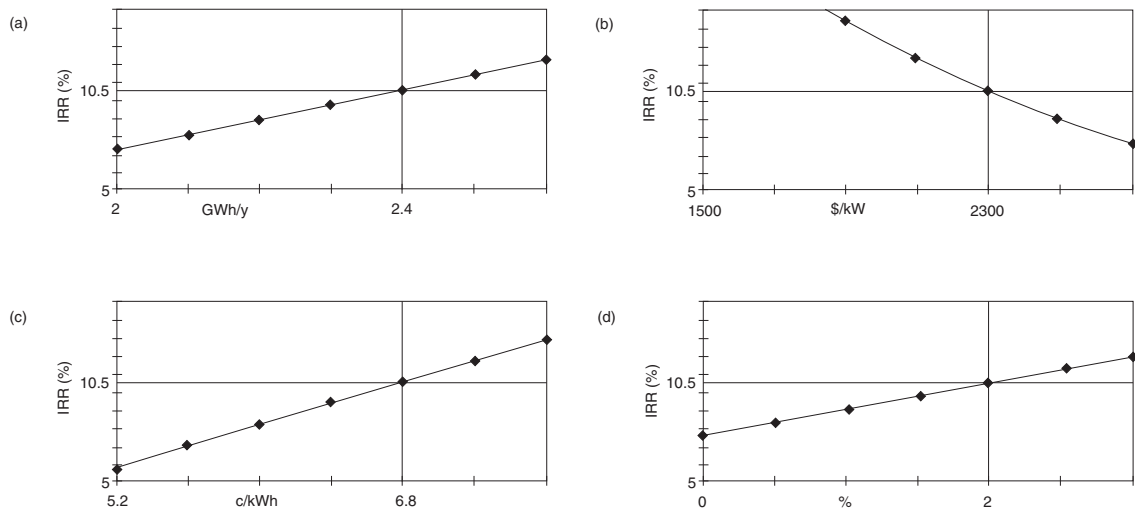
A sensitivity analysis was conducted on the base case of Biggar (1995). For simplicity, it was assumed that the loan period equals the project lifetime of the wind farm which is 20 years. The value of electricity at 6.8 cents per kWh with a 2% annual increase above inflation was assumed. Based on these figures, the IRR was calculated to be 10.5%. The sensitivity of the IRR to each of the above parameters is shown in Figure 5.14.

The effects of each parameter can be compared using the sensitivity analysis in Figure 5.15 which shows the individual effects of each parameter on the IRR. The parameters were normalised and shown as a percentage of the base figure.

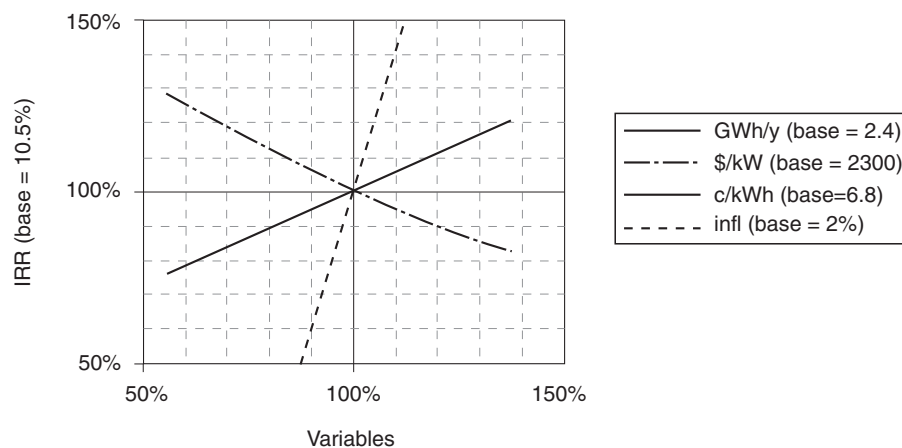
The sensitivity of the value of electricity (c/kWh) and the annual generation (GWh/y) were identical, since the revenue from a wind farm is proportional to both. The IRR was particularly sensitive to the inflation rate of the value of electricity since this had the effect of increasing the value in a cumulative manner every year.

Biggar (1995) compared his cost analysis with that undertaken by Barnett (1994) using a 60,400 kW turbine wind farm model which gave an electricity price range of 5 to 6.5 c/kWh including transmission costs of 1.2 to 1.6 c/kWh. Biggar argued that the high O&M costs of 2.9 c/kWh used by Barnett to offset risk of component failure under New Zealand wind conditions should be 1.1 to 1.4 c/kWh. However, he also suggested the

installed capital cost of around \$1450/kW calculated by Barnett was too low and that \$2280/kW would be more realistic. Biggar used a discount rate of 7.7% to obtain a base case electricity cost of 7 c/kWh. Sensitivity analysis covering several variables gave a range of 6.2 to 8.1 c/kWh.



**Figure 5.14: Effects of (a) annual energy generation, (b) installed cost/kW, (c) price of electricity and (d) inflation rate of electricity price on the IRR**



**Figure 5.15: Sensitivity analysis of the IRR with variations in annual electricity output, capital cost/kW, and value of electricity**

Henderson (1996) offered two future wind power price scenarios for consideration. His “mainstream” view was that wholesale electricity prices in the North Island would rise from 5 c/kWh in 1996 to over 7 c/kWh by 2005. In addition, he assumed Trans Power prices would rise 50% in 1997 and a carbon charge would also be applied then. This gave an overall electricity price around 9 c/kWh. Meanwhile, the wind generation costs would drop to 7 c/kWh by around 1998 and then level off to around 6.8 c/kWh by 2005.

His second scenario assumed that the current North Island electricity price of 5 c/kWh did not rise other than by around 1.5 c/kWh due to increased Trans Power charges and a carbon tax giving 6.5 c/kWh by 2005. Hence, wind power, using the current generation of imported WTGs, would remain uneconomic. His argument was, therefore, that to gain more rapid uptake of wind power the wind energy costs would need to be reduced to below 6.5 c/kWh, which could be achieved by manufacturing wind turbines in New Zealand designed to match the specific wind resource.

Overall, due to the limited experience of operating wind farms under New Zealand conditions and, therefore, the number of assumptions that need to be made, it appears that wind power on the best sites in New Zealand can generate electricity for around 7 c/kWh including transmission charges.

## 5.5 Constraints and Opportunities

The main barrier to wind power development is the economics. At present power prices, it is only viable at the sites with highest mean annual wind speeds. The uncertainty of the economic analysis, both in calculating energy production and in determining the value of the generated electricity, gives little confidence to potential investors. Other real or perceived barriers have an effect on gaining resource consents. These include possible electromagnetic, visual, noise, wildlife and other environmental impacts. Various actions can be taken to reduce or overcome these barriers.

The economics of wind power are expected to gradually improve in the next few years but would be more rapidly improved if a “green” electricity pricing structure was implemented. A future carbon tax will also have an influence on wind power economics, but due to New Zealand’s large hydro energy electricity base, the influence on electricity prices might not be large. Such incentives for renewable non-polluting electricity generation have been implemented in many other countries. In future, turbines designed specifically for New Zealand’s high wind conditions may be able to generate more electricity per unit cost than the current state-of-the-art turbines.

The uncertainty in economic calculations will be only overcome when more accurate wind turbine data becomes available from manufacturers, and more accurate conversion of site wind speed data to electricity generation becomes possible based on experience. This will require further research. There is also some uncertainty at present in the true value of electricity generated by WTGs, in particular whether the avoided Trans Power cost should be included. This also requires further research.

Electromagnetic interference is of concern to owners of telecommunication and radar equipment sited on or near to a proposed wind power site. These owners will probably object to a proposed development if they have no standards, guidelines or prior experience to reassure them that the wind farm layout will not affect their equipment. This barrier will be largely overcome by the adoption of standards and guidelines for wind turbine siting based on local experience once several wind farms become operational.

Visual impact will continue to be a major debate in consent applications to build a wind farm on a visually prominent site. The impact could be reduced by careful design of the turbines and their layout, and by choosing less prominent sites. Whether the impact is positive or negative is subjective and therefore hard to quantify or compare.

Noise from WTGs is less of a problem with modern WTGs compared with older designs, but there has been a lot of publicity and so this is often perceived to be more of a problem than it really is. People often find that WTGs are quieter than they expected when they actually hear them for themselves. Noise will only be a problem if people are living or working very close to a wind farm.

The effect on wildlife is another area where publicity has sometimes caused the impacts to be perceived to be greater than they really are. However, WTGs could cause some bird fatalities and so areas close to populations of rare species should be avoided. Research is being carried out overseas and will be monitored in New Zealand once the first wind farms become operational.

Other environmental impacts or concerns can include the appropriateness of man-made structures in natural environments, including the natural coastline.

## 5.6 Further Research

Further research to assist the development of wind farms in New Zealand falls into the general areas of WTG design, economic calculations and environmental issues.

### 5.6.1 WTG design

Manufacturers and researchers, both in New Zealand and abroad, are continuing to develop more cost effective and efficient WTG designs. Improvements are expected in areas such as fatigue, life and control systems but there is potential for designs to be produced that are better suited to New Zealand’s higher wind speeds.

### 5.6.2 Economic calculations

Areas of uncertainty in the economic calculations require further research. In particular the electricity generated by WTGs, traditionally calculated from hourly average wind speed data and averaged WTG power output curves, can introduce errors particularly at lower wind speeds near the cut-out. This, and more accurate ways to calculate the annual electricity output, need to be investigated.

Another area of immediate interest is the proposed Trans Power charge structure. Research will be required to determine how much of the Trans Power charge could be avoided by installing a wind farm to meet local demands.

Other uncertainties needing further research include O&M costs, inflation rate of electricity costs, effect of government policies on CO<sub>2</sub> emissions, and other environmental concerns.

### 5.6.3 Environmental issues

Research on environmental issues such as visual, noise, wildlife and electromagnetic interference is required on specific New Zealand aspects. To enable appropriate design and consistent and fair resource consent decisions, there is a need for standards and guidelines, particularly in the area of electromagnetic interference. Sites that are good for wind farms are often also good for telecommunication and radar equipment.

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## ***6 Integrated Energy Systems***

There are synergies between various renewable and traditional energy technologies which at times provide incentives for consumers to utilise a combination of energy sources. This section discusses how large scale renewable energy systems could be integrated into the traditional energy supply infrastructure.

An outline of small scale independent energy systems is then provided. These systems can be used by people living in rural and often remote areas, as well as isolated tourist lodges, alternative lifestyle blocks etc.

The individual technologies involved have been described in previous sections of the report so are not revisited. The principles of power generation from wind, solar, hydro, biogas etc. are similar at this small scale as at the larger scale.

Integrated energy systems were not specifically discussed at the Rotorua seminar workshops.

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## **6.1 Large-scale Integrated Energy Systems**

### **6.1.1 Technology review and New Zealand experience**

It is not envisaged that renewable energy technologies will suddenly displace fossil fuels. It will be more pragmatic for renewables to slowly be phased in once the technologies have been successfully demonstrated. As a result they will become better accepted as reliable, cost effective, and environmentally benign energy sources. This section briefly considers how renewables can be utilised alongside traditional energy supplies at the commercial scale.

Recent analyses of global energy supply and demand conditions based on fossil fuels have raised major concerns about probable market tensions within the next decade. Wide spread environmental degradation and risks of climate change are also paramount.

Total world coal, oil and gas reserves are finite but abundant supplies currently exist thereby maintaining low energy prices. Taking oil as an example, the oil shocks of the 1970s changed the resource depletion pattern. As a result of improved conversion technology efficiencies being developed, alternative fuels being used, and energy efficiency initiatives being taken up, the global oil demand decreased and prices remained low. Demand is now rising again and prices are slowly following.

It has been argued by members of Petroconsultants SA, Geneva, that already over half the total world oil resource has been consumed (Laherrere, 1995; Campbell, 1996) and that at current depletion rates, 80% of the total oil resource will have been consumed by 2020 with the remaining 20% being more difficult to access. This will put pressure on not only the energy industry but also on the chemical and materials industries that also depend on fossil hydrocarbon feedstocks.

Combined with environmental issues, particularly from coal combustion, it appears likely that many regions of the world will encounter increasing difficulties in maintaining their historic rates of growth based on fossil fuel use. In New Zealand, the limited life of the known natural gas reserves is beginning to cause concern since gas currently provides approximately 40% of the total annual primary energy supply.

It is therefore appropriate to continue to evaluate and develop a range of renewable energy resources and technologies which can increasingly contribute to the nation's energy supply. There will not be a single solution to the fossil fuel substitution problem, rather a miscellany of renewable energy applications to suit specific energy demands.

Based on the previous sections of this report and supported by the data in the earlier report "Renewable Energy Opportunities for New Zealand" (Ministry of Commerce, 1993), the total potential renewable energy resource in New Zealand far exceeds the current annual energy demand. However in most cases the renewable technologies have not proved cost effective when competing with cheap fossil fuels, the exception being existing large hydro power schemes which currently supply around 70% of total electricity demand.

The Massey University Energy Database, being the most up-to-date energy flow data available on New Zealand's primary fuel supplies, conversion processes, and final use sectors, shows the total annual energy demand is around 400 PJ arising from the primary energy supply of 640 PJ per year (Dang, 1995). Approximately 95 PJ (24,000 GWh of electricity) is obtained from hydro and geothermal sources and 28 PJ from biomass. The remaining 280 PJ is currently supplied by gas (40 PJ), liquid fuels (170 PJ), coal (45 PJ) and other electricity sources (25 PJ). (Centre for Advanced Engineering, 1996).

Renewables could, in theory, provide energy in the desired forms of heat, motive power and electricity to the extent provided by the range of traditional energy sources at present. To compete with fossil fuels, energy from renewables must be provided not only cheaply and in the desired form, but also at the time and place desired by the consumer.

The infrastructure necessary to supply fossil fuels to meet the seemingly ever increasing demand is well established and includes road tankers, pipelines, coastal tankers, the national electricity grid, and delivery of coal by rail. Delivery of energy from renewables would be more difficult due to the more dispersed nature of the resource, whether it be using wind turbines, solar roof panels, fields of energy crops, forests, or wave installations. This wide distribution will encourage local use of renewables where feasible in order to

minimise energy distribution costs. Since the renewable sources are dispersed, private companies, utility companies, local authorities and energy developers will tend to harness the available energy for their own use or for sale to local consumers. The 34 MW cogeneration plant being constructed by Carter Holt Harvey at its Kinleith pulping plant is a good example (see section 3.2.4). The primary energy source is to come from process waste products such as the bark, already collected on site and bringing a disposal cost associated with it. The heat and power produced by the plant are to be used on site. Other cogeneration plants, such as at the Forestry Corporation's Waipa sawmill, export excess electricity.

Decentralisation of the energy supply is likely to continue as more renewable projects come on stream. Already many examples exist of communities, both in New Zealand and overseas, meeting all their own energy needs using a range of technologies as diverse as wood burning, anaerobic digestion, wind, solar and micro-hydro. In the future, New Zealand local authorities could conceivably own and operate nearby wind-farms; encourage solar thermal panels on every roof; promote passive solar building design concepts; produce methane from the landfill and sewage plants; irrigate energy forests and crops with municipal wastewater to give land treatment; and convert the biomass produced into heat, power or transport fuels for local use.

In the longer term, it is not beyond the realms of possibility for a building to have efficient PV modules incorporated into the roofing and cladding materials and for the electricity generated to be used on site for electrolysis of water to produce hydrogen gas. This would be stored and later used in the building's independent fuel cell to supply all the electricity demand. In this future scenario, where the building was a household, there would be two vehicles in the garage, one an electric commuter vehicle charged by the fuel cell, and the other a longer range vehicle fuelled by the hydrogen directly. Better still, there would be only one vehicle but with dual fuel capability for short or long journeys. These scenarios serve to illustrate that renewable energy sources are more likely to be located and consumed close to the point of demand than to be carried large distances.

### *Energy supply mix*

With the exception of embedded generation (see below) where renewables such as landfill gas, MSW incinerators and wood-fired boilers are stand-alone systems, phasing in of renewable energy resources may best be achieved by mixing them with traditional fossil fuels using a range of methods as exemplified below.

- Co-firing of coal and fuelwood chips in existing boilers.
- Blending of ethanol or biodiesel with petrol or diesel.
- Linking wind farms to the local electricity distribution network rather than the national grid to provide a means of reducing thermal power generation, assuming wind power is taken and used whenever available. Whether this happens in practice will depend more on the spot market power price and on the public support for "green energy" rather than on the altruistic generosity of local power companies.
- Large scale tidal, wave or off-shore wind technologies could also reduce thermal power generation but not only would the coastal environmental implications of such installations cause debate, the power lines and pylons needed to transfer power to the load centres would also create planning issues.
- At the small scale, linking wind power with a diesel generator to reduce the diesel fuel consumption, but not necessarily totally displacing it as the diesel provides a reliable backup (see section 6.2.1).
- Blending methane produced from landfill gas or biogas plants with natural gas and reticulating it to consumers in existing pipelines.

In all of these examples it would be technically feasible to displace all the traditional energy supplies by the renewable energy source. However, mixing the sustainable energy source with the fossil fuel source will provide time, both for confidence to be established in the reliability of supply of the renewable resources, and for the continued development of the new technologies to improve their conversion efficiencies and cost effectiveness.

### *Availability of renewable energy supplies*

Public expectation is that energy will be immediately available whenever needed, whether filling up at a petrol

station, turning on a light switch or opening a gas valve. Renewable energy supplies can be less reliable. Daily and seasonal variations in energy demand are difficult to match with some forms of renewable energy which have intermittent and unpredictable supplies. For example wind, solar and wave power are weather dependent (as is hydro power, but to a lesser degree depending on the built-in storage buffers of the lake behind the dam). Tidal power is intermittent but entirely predictable, though not necessarily coinciding with peak demand loads as the peak generation time changes daily with the tide. Biofuels are the only renewable energy sources which, like fossil fuels, can be easily stored for short or long periods to meet variations in demand.

Heat can be practically stored for short periods of only a few hours so daily fuel supplies are required. Some base load low grade water heating ( $<100^{\circ}\text{C}$ ) and medium grade process heat ( $100^{\circ}\text{C}$  to  $300^{\circ}\text{C}$ ) could be met in the future by using heat from cogeneration schemes, combustion of biofuels, and solar thermal systems. Providing a reliable heat supply for space heating in the winter and to the varying degrees required depending on the fluctuating ambient temperature, is more difficult.

Electricity has to be generated to meet instant demand as it is very expensive and therefore impractical to store. Therefore, a mix of generation from wind, hydro, solar and geothermal is feasible, with perhaps biogas and bioenergy used to meet peak demands.

In effect the wind and solar power could be used to maintain the hydro lake levels to give greater storage capacity, which is relatively low in New Zealand at present. The newly established wholesale electricity market will need to determine the value assigned to this additional stored capacity. Pumped storage systems are used overseas to meet peak demands, water being pumped (using electricity during periods of low loads), to a higher level store which can be brought on line to meet peak power demands in only a few seconds. No such schemes operate in New Zealand.

Liquid and gaseous biofuels can be stored as for petroleum and natural gas without problems. Methane from biogas is usually stored under pressure as is CNG. Tests on biodiesel and ethanol have shown there are no problems of deterioration with prolonged storage.

Overall the reliability and flexibility of hydro, geothermal, and biofuels have advantages over wind, solar and wave energy which are weather dependent. Weather forecasts can help to predict power inputs from wind, solar and wave and a geographic spread of sites would even out fluctuations in national power supply to some extent. Reducing the grid load demand by up to 20% by using intermittent renewables should not be a problem. At contribution levels from renewables closer to 50%, a more flexible supply system would need to be developed, and include more power plants with rapid response times (Grubb, 1991).

### ***Scale of Supply***

Different types of renewable energy technologies can be scaled and integrated to fit appropriately into the various levels of a nation's electricity supply system. This section briefly discusses the application of technologies at low levels — grid supply, embedded utility generation, distributed generation within a network, and isolated supplies in remote areas.

#### ***Grid supplying generation***

The national grid could facilitate the development of a wide variety of complementary renewable energy forms. The principal issues for grid supplying generation are the same, albeit of a different scale and complexity, as those for remote area power supply systems (RAPS) covered in section 6.2. The grid can help to connect generation and storage and also to deal with control issues.

Renewables, hydro and geothermal specifically, are already the main form of grid supplying generation in New Zealand. Over the next ten years, new renewables are likely to be designed as embedded or lower level generation, although some facilities may be configured so that they can supply the grid. The most likely candidates for grid connection would be remote or very large wind farms and large biomass based plants at industrial sites already connected to the grid. An example of the latter is the new wood residue boiler to be installed at the Kinleith pulp and paper complex.

#### ***Embedded Utility Generation***

This refers to power generation in excess of the needs of a single building or industrial site, but not more than



the demand of the surrounding local network. The generation itself may provide cost effective energy and it could also provide savings by helping to avoid a national grid upgrade where demand is rising. Whether this latter benefit can be quickly captured and passed to consumers is not clear under the present transmission charging regime.

Appropriately placed embedded generation can mitigate local network power quality problems such as voltage control, especially those experienced on the periphery of the network. It can also help to avoid the need to upgrade parts of a local network. A wide variety of renewable technologies are likely to be applicable to embedded generation in New Zealand. Prime candidates are wind power, small hydro, landfill gas and other biomass-based cogeneration schemes.

A problem that can detract from the benefits of embedded generation is lack of energy storage. Generation fluctuations are usually smoothed by importing power from the national grid. This means that there must be grid connected renewable-based power stations with storage facilities or fossil fuel backup plant. New Zealand has a largely hydro-based power system with enough storage to deal with the short term shortfalls in embedded generation. Nonetheless, lack of embedded storage can mean a financial penalty for the utility company.

An existing future prospect for national grids is the use of super conductors. These materials can almost eliminate transmission losses and in the future may mean that power can be cost effectively conveyed over long distances at low voltages. The implications for renewables would be dramatic. It may become feasible to grid connect even small-scale geographically remote renewable energy sources.

Technological developments are expanding the possibilities for energy storage and hence the likelihood that a utility will have access to the requisite natural resources. Conversion of electrical energy to chemical energy and its later reconversion is a possibility for embedded systems. Storage options, suited to the scale of embedded generation that applies in New Zealand, are available. Figure 6.1, for example, shows a range of compressed air possibilities. These rely on the presence of suitable geological formations. Hydrogen from electrolysis is another possibility, but better suited to grid-scale generation.

### *Distributed Generation*

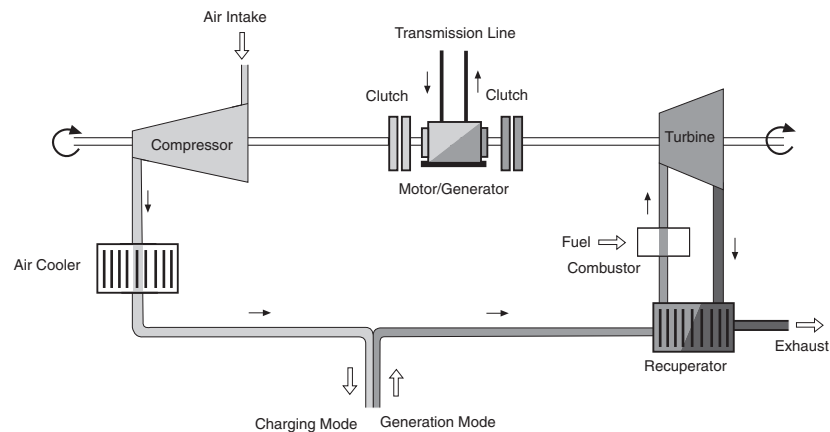
Distributed generation technologies are similar to those that can be used for smaller RAPS systems. The difference is that the technology supplies homes and offices that are connected to a local power network. A variety of factors may favour distributed generation. The high cost of peak power to office buildings, for example, may encourage peak shaving using PVs to supply midday air conditioning loads. The need to upgrade a local network supply line to an expanding community could be avoided by a combination of measures including energy efficiency, use of natural gas for water heating, and distributed generation.

Distributed generation needs to have low impact on amenity values to be able to fit in to the city and suburban environments. The most likely candidates for distributed generation are PVs, solar thermal, daylighting and passive solar technologies. There is a trend towards integrating the energy collectors with architectural forms (see section 2.3). Approaches include special passive solar office walls, PVs built into house roofing tiles, and solar water heaters installed flush with roof lines. In some cases, small-scale wind turbines may also be appropriate in built-up areas and could also be integrated into architectural forms. This particularly applies to the small vertical axis machines now available.

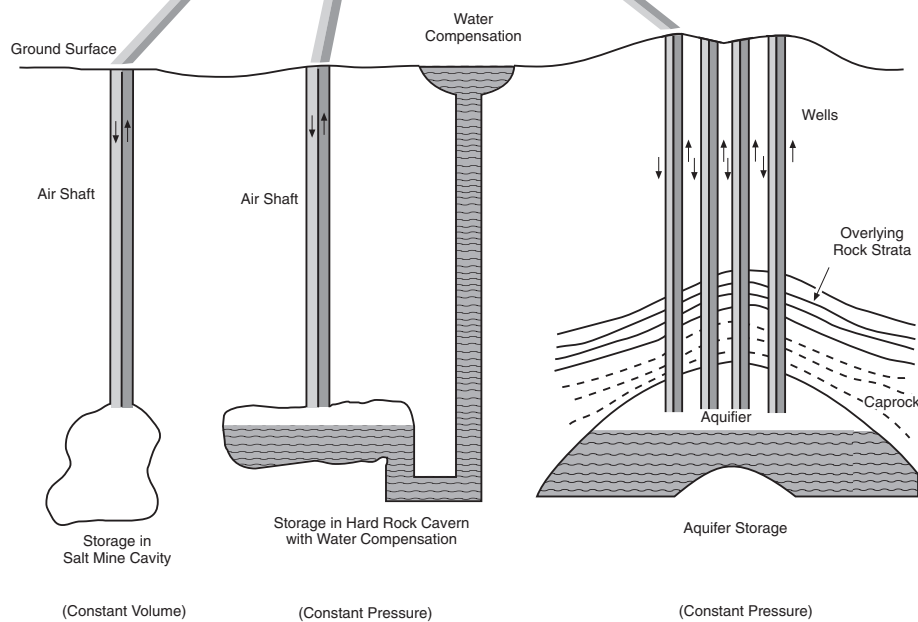
It should be acknowledged that cogeneration at offices, swimming pools and factories is a form of distributed generation. Biomass in the form of wood process residues is used in industrial-scale steam boiler cogeneration schemes in New Zealand (see section 3.1). In future, commercial and institutional buildings could have cogeneration plants based on renewable derivatives such as hydrogen and ethanol and using such technologies as fuel cells, to provide heat and power.

Cogeneration aside, the main emphasis for distributed generation overseas appears to be the PV technology with household programmes such as the PV Pioneers scheme in California. Notwithstanding the flexibility that electricity from PVs can provide, solar thermal should not, however, be seen as the poor cousin. Figure 6.2 shows a solar thermal system developed for use in Australia, which can supply more energy utilities than just hot water. The key to deriving flexibility from solar thermal systems is to generate high temperatures. Figure 6.3 shows an evacuated tube collector under development which could cost effectively provide steam.

## Compressed Air Energy Storage



## Compressed Air Reservoir Types



**Figure 6.1: Compressed air energy storage systems**

Another noteworthy development is trickle feed systems which continuously supply electricity via low capacity lines to home storage batteries. Household demands are drawn from the storage. In some cases, the cost savings in local network supply infrastructure and peak generation facilities could outweigh the expenditure on home storage and controls. Trickle feed systems create an immediate synergy with distributed PV or wind generation. Once installed, the storage can be supplied by trickle feed or an immediate renewable source.

### *Isolated supply systems*

Remote area power supply (RAPS) systems have long been used to provide electricity to farms and other businesses beyond the coverage of a national grid-supplied local network. Increasingly though, people are opting to install their own isolated power supply system even where connection to the grid is practical. The reason, in most cases, is the high cost of installing transformers and supply lines to connect to the local network, or a high voltage transmission line.

There is a very strong synergy between energy efficiency and RAPS installations. RAPS power tends to be expensive and consequently super efficient refrigeration, lighting etc. becomes imperative. The cost of RAPS power is decreasing, however, and the security of supply is improving as a result of a move towards integrated systems. These systems may still be based around the traditional diesel generator, but also use wind, micro hydro and or photovoltaics to supply a significant amount of power.

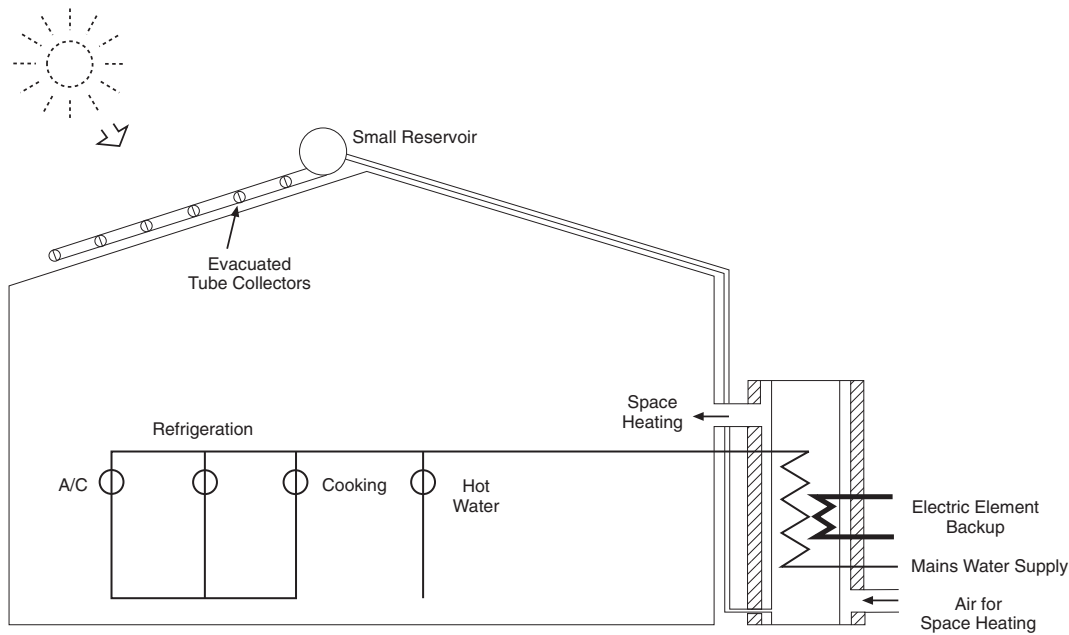


Figure 6.2: Solar thermal collector and storage system solar house retrofit project

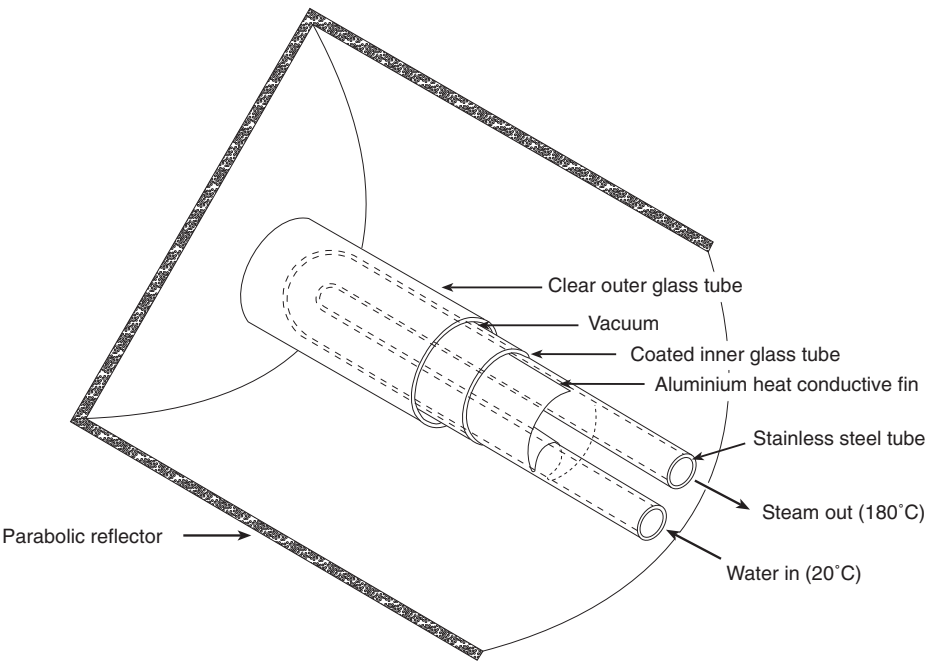


Figure 6.3: Solar thermal heat collection device

**Energy storage**

Storage issues can be addressed in several ways. Firstly, local resources may be available to provide storage capacity. For example, a small hydro scheme could be developed in train with a wind farm proposal. Secondly, the utility could look to its neighbours and develop cooperative arrangements with other utilities developing renewable schemes with some storage capacity. The possibility to develop energy management

programmes with utility consumers should not be overlooked. These programmes can cover measures such as on-site energy storage in the form of hot water at a food processing site for example, through to load shedding strategies.

Hydro is an obvious form of storage for the New Zealand grid-supplying generation system, but overseas research on alternatives such as hydrogen should not be overlooked.

Pumped storage of water and conventional battery storage systems are practical, but expensive storage options mainly at the large and small scale respectively. More advanced batteries are under development and flywheels can also be used for short term storage. In the longer term, storage in superconducting electromagnets may become a feasible proposition.

For electric vehicles, lead-acid battery storage is the only current option but somewhat impractical (except for commuter vehicles perhaps), due to their heavy weight, high cost, short life and limited range. Lithium difluoride batteries have considerable weight advantages (2300 Wh/kg versus 44 Wh/kg for lead-acid batteries). Lithium extraction from sea water or geothermal water is expensive and energy intensive so supplies come from conventional land mining techniques but are limited. A lithium processing plant planned in New Zealand to extract 600 t of lithium per year from seawater using a new technique holds promise for cheaper supplies.

The use of renewables to produce the intermediate fuel, hydrogen, is worthy of consideration as an alternative approach for the future. Hydrogen can be easily stored, is non polluting when burned in air (except for very small amounts of nitrogen oxides perhaps) and, when used in fuel cells, emissions are zero. Car manufacturers such as Daimler Benz have demonstrated use of this technology. Hydrogen is already produced in large quantities and shipped around the globe to supply the chemical industry. It can be produced by re-forming methane from natural gas or biofuels but carbon dioxide is the unwanted by-product. Hydrogen gas can also be produced by electrolysis of water using electricity generated from either conventional or renewable sources. Thermal dissociation of water using concentrating solar collectors to give temperatures over 2000°C is a third method to produce hydrogen but is even more expensive.

Hydrogen can be stored in the gaseous or liquid form but its small atomic size makes it difficult to contain. Storage options include underground reservoirs. An alternative and safer form of storage is in combination with a metal to form a hydride. The process can be reversed by heating and 500 l of H can be stored per litre of container volume. Hydrogen can be transported in bulk in liquid form, in insulated low temperature tankers, or pumped in pipelines as a possible replacement for reticulated natural gas. It has a lower calorific value than natural gas and can permeate seals and other pipeline materials. Storage problems are not insurmountable and the future may well involve a strong connection between electricity and gas supplies.

Currently hydrogen fuel would be an expensive option but there is future potential for cheaper production methods. Research projects to evaluate hydrogen production from renewables include:

- using photovoltaics in the Saudi Arabian desert and shipping the hydrogen produced by tanker to Germany for use in a range of modified vehicles; and
- using hydro power in Quebec for electrolysis of water with the hydrogen to be transported to Hamburg for use in a public transport system and in an experimental aircraft.

Research on hydrogen fuels in New Zealand is limited but includes small scale solar/wind/hydro/hydrogen systems and a prototype plant has been constructed. The hydrogen produced is currently used for cooking and to power a converted refrigerator. In addition, Canterbury University engineers are undertaking studies of hydrogen-fuelled engines.

### **6.1.2 Economic and environmental issues**

It is difficult to generalise over the costs and benefits of integrated energy systems at the commercial scale. Each project would be very site specific and the viability of using renewables would be highly dependent on the prevailing weather conditions, scale, current energy supply, delivered costs, proximity to the renewable energy resource, variations in demand, reliability of supply etc.

Every proposal to integrate renewables with traditional energy will need a detailed feasibility study to be

undertaken, including details of the proposed site for the conversion plant and the prevailing weather conditions. A full cost/benefit analysis of whether to stay with traditional energy sources: change totally to renewables, or have a mix of the two will be required.

Integrated electrical energy systems have an inherent environmental benefit in that they avoid wasted energy from transmission losses when the power is used locally. However, the environmental concerns (indicated within this report on each technology) from visual impact, to land use, to ecological damage, would need to be thoroughly examined for each individual proposal.

### 6.1.3 Case Study: sewage treatment plant Fehmarn Island, Germany

The treatment plant receives the total sewage from the island town of Burg and the holiday resort Burg-Tiefe giving increased summer loading. The main electric load for the plant is sourced from a 250 kW wind turbine and a 140 kWp photovoltaic array powered respectively by a 6 m/s average wind speed and a 3 kWh/m<sup>2</sup>/day solar radiation input. Increased solar gain in summer matches the increased demand from the holiday makers. Grid connection is present both for backup and to export the surplus power generated.

The solar array consists of 3840 modules in 11 rows at 7 m spacing. To provide 410 V DC, 160 groups of 24 modules are connected in series providing a nominal current of 370 A. The controls, designed by Telefunken System Technik, include two 80 kVA pulse inverters to feed power into the 3 phase system.

The wind turbine has a rotor diameter of 25 m, a cut-in speed of 4 m/s, and generates peak power of 250 kW between 14 and 23 m/s.

System reliability is provided by a biogas driven backup generating set. A Daimler-Benz engine drives the 30 kW synchronous generator. Biogas is stored in a 300 m<sup>3</sup> reservoir as a short-term energy store. Engine heat is used to provide process heat to maintain the digester at around 35°C.

An operation management control system monitors the operational data, compares the energy profile with meteorological data and adapts the energy profile to the load profile. It also manages the load to match the energy available by utilising the internal inertia of the sewage treatment plant components, connecting and disconnecting them as appropriate (Figure 6.4).

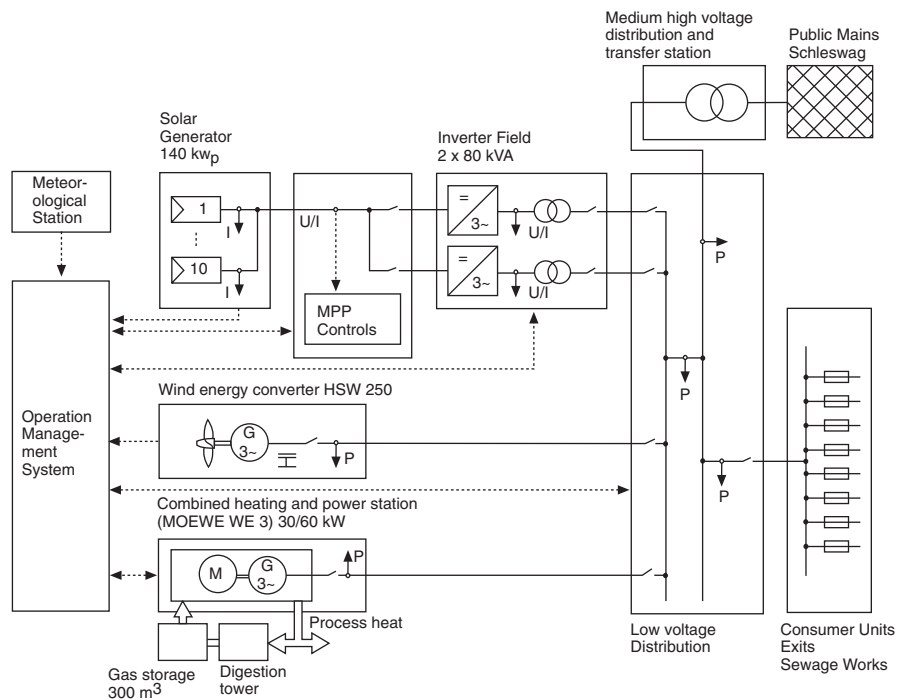


Fig. 6.4: The power generating system for the sewage treatment plant on Fehmarn Island (Mertig, 1990)

Over a 12 month test period the load demand ranged from 18 MWh/month in February to 37 MWh/month in July and August. Energy supply from solar, wind and biogas ranged between 31 MWh in November to 57 MWh in April and November. Surplus power was generated each month but around 5 MWh/month was imported from the grid for the short periods when insufficient power was available.

Following testing and refinements to the system the wind turbine generates 490 MWh/year, the photovoltaic array 140 MWh per year and the biogas genset, 105 MWh per year. Annual load by the sewage plant was 350 MWh of which 60 MWh is supplied by the mains. This leaves 465 MWh for export sale to the grid.

The technology has been successfully proven at this scale, which would also be appropriate for a small community. An economic analysis was not available.





## **6.2 Small-scale Independent Energy Systems**

### **6.2.1 Technology review**

For isolated rural communities, inhabited islands, tourist lodges and farms not served by an electricity distribution grid nor other readily available energy supplies, independent energy generation systems may be warranted. In addition, new rural electricity consumers only a relatively short distance from a power line are now investing in independent power generation systems, to avoid power line installation and connection costs which range from around \$15,000 to \$25,000/km of line.

Some power companies have already increased their fixed supply charges to existing rural consumers to offset the higher line maintenance costs per user. If this approach continues, more consumers near the end of the line will consider installing independent systems and the rural electrical network will begin to unravel.

Wind/solar power supply systems have also occasionally been installed in urban areas, though this is usually by self sufficient enthusiasts rather than for economic gain.

Such systems are commonly known as remote area power supply systems (RAPS); integrated renewable energy systems (IRES); integrated power supply systems (IPSS); or autonomous energy systems (AES). The most appropriate term is difficult to conceive since the systems are no longer necessarily “remote”, not always solely “renewable”, sometimes used to supply energy in forms other than electric “power”, and not exclusively “autonomous”. Other terms used include “hybrid” systems and renewable energy hybrid systems (REHS) where a diesel generator is not a system component. In this paper RAPS will be used for convenience although not always strictly correctly.

### **Technical status**

All the above systems utilise two or more energy sources (usually both renewable), and the appropriate end use conversion technologies to supply a variety of energy needs often in a stand-alone mode. The renewable energy sources used are usually wind, solar, hydro or biomass in the form of biogas or fuelwood. These can function either in conjunction with more conventional energy systems such as diesel generating sets, or in combination with each other, to meet demands for medium grade heat, low grade heat, rotating shaft power or electricity.

Alternative transport fuels are not considered here as they are unlikely to become viable at the small scale in the short to medium term, although enthusiasts have run vehicles on ethanol from wheat, producer gas from wood and vegetable oil from oilseed rape. Compressed scrubbed biogas is an exception which could be used economically in a CNG converted vehicle in some specific circumstances. Small electric vehicles might also have a place in certain situations, the Zermatt tourist resort in Switzerland being a classic example where only electric vehicles and horse drawn carriages are permitted.

Two options are possible for users of independent renewable energy systems; either to convert all the energy resources to one form, normally electricity, for ease of storage and supply, or to match the different resources to the various needs using appropriate devices to give an integration of benefits to the user. The latter can prove more economic than the former depending on the cost of appliances and conversion systems. For example RAPS electricity could be used only for lighting and powering electronic goods, with biogas used for cooking, biomass for space heating and solar thermal for water heating.

It is normally recommended for a RAPS user to substitute other sources of energy for electricity wherever possible to minimise capital costs.

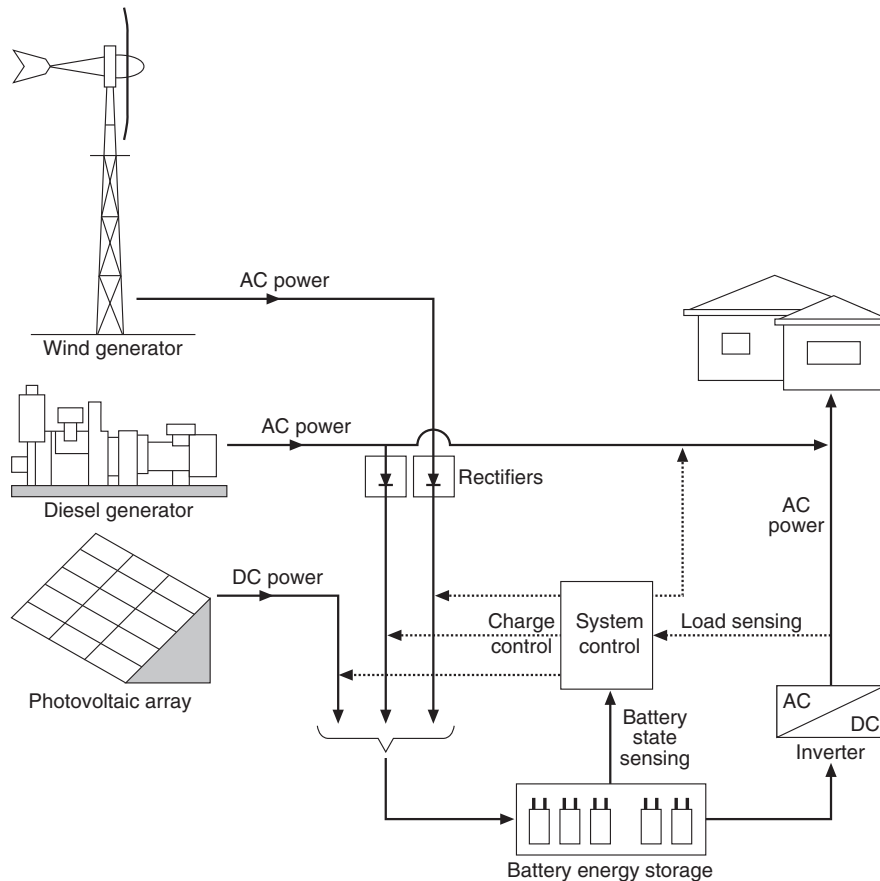
Other energy sources include firewood for space heating, LPG for cooking, and solar for water heating. The development of efficient wood burning stoves, the nation-wide availability of LPG, and improved designs of solar water heaters at lower costs have facilitated this recommendation.

Electric appliances should be selected for energy efficiency and used accordingly. Specially designed super-efficient refrigerators, for example, are essential and use far less power than a 5 star rated standard refrigerator. The extra capital cost of these appliances however must be offset by the savings in generation capacity or storage requirements of the power generating system.

### System elements

Diesel or petrol engines used to drive an alternator provide the primary source of electricity in many RAPS systems. As a stand-alone unit, the generator's running hours tend to be extensive and often only supply light loads. When there is no load the engine can be shut down either manually or automatically and automatic ignition can be installed for when an appliance is switched on. Alternatively the generator can be combined with a battery bank so that it charges the batteries to increase the load when running which would extend its life and reduce the total running hours per day.

Diesel/petrol generating sets have high operation and maintenance costs, are noisy and produce exhaust emissions. They can be coupled with PV and/or wind power generating systems to reduce the fuel consumption. The layout of such a parallel hybrid system using two different renewable power sources (one AC and one DC) and a diesel generator is shown in Figure 6.5.



**Fig. 6.5: A combination wind/diesel/PV parallel system suitable for a remote area power supply application**

Generators are selected from the fairly small range available. Typically wind turbines are usually in the 1 to 15 kW range and PV panels can be added as required in multiples of say 55 to 75 W(p).

Micro-hydro systems can be utilised where a water supply with suitable flow and head is available. The water turbine directly drives the generator (see section 4.1). The installation requires construction of an intake and diversion weir capable of withstanding flood conditions, a penstock, and a tail race. Water rights are always required to be sought from the local Regional Council.

If the water supply is reliable then electricity can be generated 24 hours a day throughout the year. A diesel generator backup may therefore not be required depending on size of load. A heat sink to dump surplus power will be essential.

Battery storage is often a key component of these systems and lead-acid, deep cycle batteries are recommended to give adequate and cost-effective storage. They can be connected in parallel and/or series depending

on current and voltage requirements. Regular maintenance is required. The selected storage capacity in terms of ampere-hours depends on the size of the generating components, the load, and the site weather expectations. Storage to meet total demand for three days is a useful guide to obtain a reasonable reliability for the system but without excessive battery costs. Battery technologies being developed for electric vehicles may have future applications for RAPS. These include ultra-capacitors and flywheel storage.

An inverter is necessary unless only 12 V and 24 V DC appliances are operated. These tend to be expensive due to a limited demand, so conversion of DC power to 230 V AC is more usual. Square wave, solid state inverters are cheapest but have limited application. Modified or stepped square wave inverters are better but are more expensive. Since wave inverters suit most appliances they are normally recommended even though they are the most expensive. Inverter capacity must be sufficient to run the appliances used and 3 to 4 kW is common. Often the inverter is combined with a battery charger system regulator, but other designs are capable of phase synchronising to feed back into the grid.

Installations of power systems have to be carried out in accordance with the NZ Electrical Safety regulations. Low voltage systems draw a higher current so cabling, switches, fuses etc. must be carefully chosen to suit.

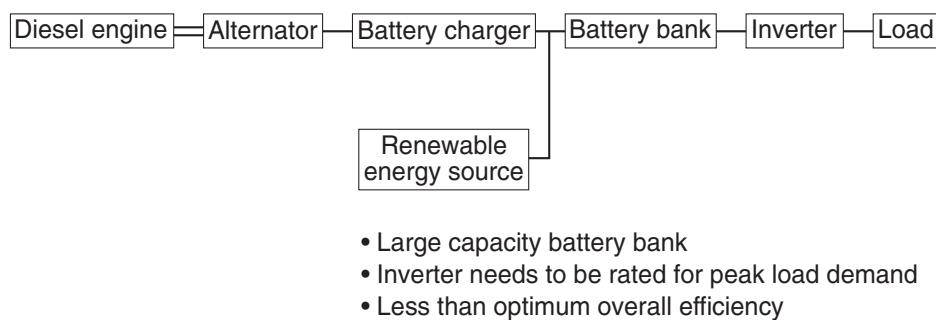
Control systems are costly so the more inefficient autonomous systems tend to have poor control capability. An effective automatic control system is needed to manage power generation, to monitor loads and the inputs to storage and the supply to load, and switch plant as outlined in Figure 6.5. Automatic controls are preferred and excellent technologies are available and continually being improved.

A meter to show battery voltage levels, and placed in a strategic position enables the user to keep a close eye on the current storage level and if necessary, modify lifestyles accordingly.

### *Systems and applications*

Wind/diesel systems with battery storage and inverter are a popular combination. The German company SMA provides such systems ranging from 30 kW to 5 MW. These systems can cope with a load up to three times the diesel generator output capacity for short periods. This combination allows optimal system efficiency; efficient operation of the diesel engine; use of small diesel gensets; use of smaller battery banks than wind alone; and diesel fuel savings potential.

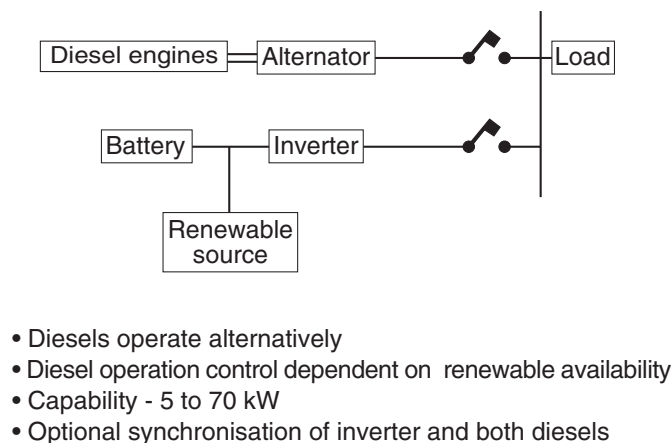
A range of hybrid power supply systems of varying energy efficiencies and costs are available. Figure 6.6 shows the arrangement of a series hybrid system with a battery bank interposed between all energy sources and the load. While this is the simplest system, it can result in inefficient diesel operation or wasted capital investment.



**Figure 6.6: General layout of a series hybrid power supply system**

Diesel generator output is limited to the peak capacity of the battery charging operation plus any load demand at that time. Large battery banks may be needed to have the diesel operating near full load. Attempts to operate the diesel engine efficiently will be frustrated by the tendency of the load to fall as charging progresses. With a larger battery bank, the diesel may only be used for a fraction of the time, resulting in under-utilisation of capital investment. During periods of peak end-use demand, the capacity of the inverter could be a limitation. Again, this can be dealt with, but at the expense of investment in a larger capacity inverter unit. The design aim should be to have two to three days battery storage capacity coupled with a small diesel generator run at peak efficiency using strategic controls.

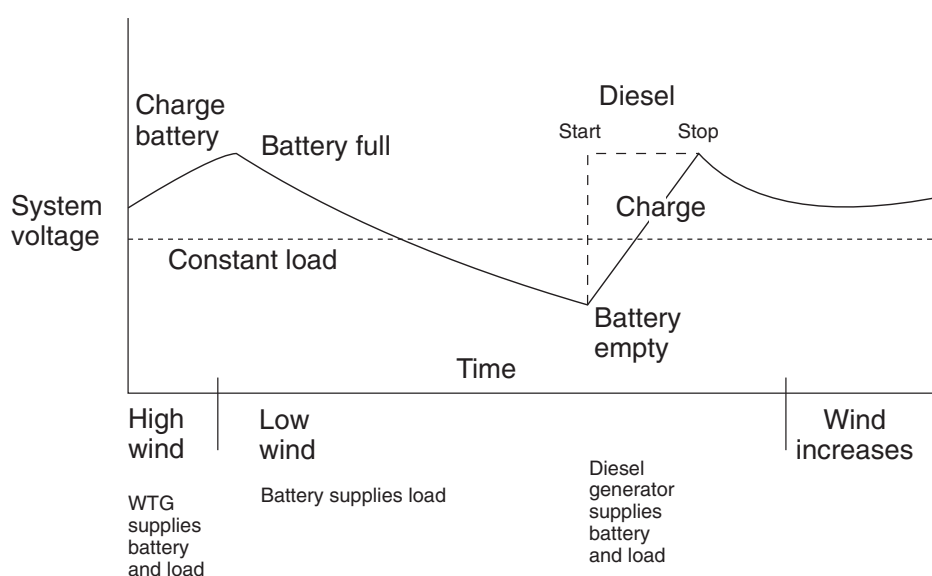
At the other end of the scale is the parallel unit shown in Figure 6.7 suitable for 5 kW to 70 kW units. During periods of low to medium loads, the system relies on the inverter only. If the load exceeds the inverter capacity (or the battery bank is low), then the diesel alternator is started and its alternator is operated synchronously with the inverter. Thus the diesel operation is controlled by the availability of the renewable energy sources. The system is arranged so that the diesel operates at or close to full load when it is running. For a large capacity system with variable load, two diesel engines might be used which would operate alternately. Synchronisation of the inverter and diesel generator is possible. Any surplus power from the alternator can be fed back through the bidirectional inverter to the battery bank. An alternative system could have the diesel engine connected to a DC generator as well as an alternator to allow battery charging.



**Figure 6.7: General layout of a parallel hybrid power supply system (CAE, 1996)**

Under low load operations for the system in Figure 6.7, switch A opens and B closes. A reserve load such as water heating for dumping power is necessary for when the wind power generation is too great. As the load increases to a medium level and exceeds the inverter capacity, or the battery bank is low, the diesel engine starts up, switch B closes and the alternator meets the load demand and also charges the battery. When fully charged B opens again. For high load operations both A and B are closed and both the generator and the batteries supply the power. Solar/diesel systems can be designed to operate in a similar way.

A typical cycle of a wind/diesel/battery system over a period of several hours with fluctuating wind conditions is shown in Figure 6.8.



**Figure 6.8: Variations in battery voltage levels of a wind/diesel system supplying a constant load over a period of several hours as the wind speed changes**

### *Isolated Power Plant*

Windmills, photovoltaic panels, and petrol and diesel engines are the most common source of energy for an on-farm task well away from the main farm centre. These sources are used to pump water for stock and irrigation, power electric fences and perhaps provide power for little-used remote station huts etc. Quite often, the tasks can cope with an intermittent energy supply (perhaps buffered, such as by using large water storage tanks in the case of stock water). In other installations the need for energy is so infrequent that some inconvenience can be tolerated. As a result, isolated systems are usually based on a single energy source rather than a more expensive hybrid system.

The installation and operation of these systems is often testament to the ingenuity of rural folk. Rather than catalogue the various types of technologies that could be used for an isolated power supply, an example is given of one recent technological development by an Australian farmer. This may further encourage people on the land to consider whether they can come up with ingenious solutions to their on-farm energy needs.

The Australian farmer was faced with the need to pump water from a river for irrigation. The result was the development of a new device, the Tyson Turbine, named after its inventor (see section 4.2.1, Ocean current). The pontoon-mounted water turbine uses the natural flow of a river to pump water or generate electricity. The turbine is constructed of one piece of moulded polyethylene and is available in 1.5 and 2.0 m diameters to suit different conditions. The turbine is suspended below two pontoons. The flow of river water turns the turbine, which is attached to a right-angle gearbox. Power from the gearbox drives a pump or a generator (or both simultaneously) on the pontoon (see Figure 4.10).

A minimum river flow rate of 0.75 m/s is required for effective operation. Indicative pump outputs are 400 m<sup>3</sup> per day at low head with the small unit to 100 m<sup>3</sup> per day at a head of 100 m over a distance of 800 m for the larger unit. Power output varies from 1.5 to 3 kW depending on the size of unit and river flow. By matching the river flow, pump barrel size, turbine size and pumping duty, high performance output can be achieved.

The Tyson Turbine is under investigation for harnessing tidal energy in remote areas of Australia. It is also being tried out in such remote places as the Himalayas, where very fast flowing rivers are available. With its abundance of swift rivers, New Zealand may also have situations where this unit could be a cost effective power or pump energy source but none have been installed to date.

Another Australian micro-hydro generator is the “Platypus”, which can provide continuous power within the 300 W to 2 kW range. A stainless steel Pelton wheel drives a permanent magnet alternator to deliver power from low head sites. It is claimed 350 W can be generated from a flow of 20 l/s at only a 4 m head. The unit can be adjusted to develop maximum power from seasonal changes in flow.

### *Application limits and synergies*

A knowledge-based design approach is needed to minimise total capital costs at a predetermined reliability level. This level can be quantified by determining the acceptable probability of a loss of power supply. Matching of the energy resource available to the demand is based partly on economics but also on the quality of the energy supply desired and the characteristics of the local resource in terms of average mean annual wind speeds, total sunshine hours per year, or the average and minimum flow rates of a nearby waterway.

The objective of the design procedure should be to obtain the size and ratings of the conversion and storage devices selected to supply energy to the various loads at minimum cost and at the determined level of reliability. As for larger scale installations, wind and solar are highly stochastic and site specific whereas biomass and hydro are more predictable, though there may be seasonal and site specific variations in factors such as crop yields or water flows. The load demand must be known for good design to occur but this is not always possible. Some loads are predictable, others not, and load data is not always available.

An example of a knowledge based design approach to a RAPS system was given by Ramakamar et al (1992) as outlined below.

- Divide the year into seasons with different resource availabilities and load requirements.
- For each season find the area of solar thermal collection needed to satisfy low grade heat demand.

- Determine the rating of wind mechanical conversion systems needed to supply shaft power (e.g. for water pumping).
- Ascertain biomass/biogas volumes to supply medium grade heat.
- Determine the electrical load including any heat or shaft power demands unlikely to be met from the other sources above.
- Select the appropriate electricity generating systems for the site, using micro-hydro if there is a suitable water supply; a gas engine if surplus biogas is available; and wind and/or PV for the remainder.
- Find ratings for the wind turbine generator, PV cells and batteries to satisfy the load and chosen reliability, and based on the available equipment as specified in a database.
- Calculate the capital costs of the possible component combinations.
- Select the cheapest combination.

A simple computer model to aid component selection decision making based on the weather data for a given site was developed at Massey University (Weiss, 1992). The procedure is outlined in Annex 6.1. A number of other similar models exist.

In Australia for example Orion Energy have developed a computer model to enable economic comparisons to be made between grid connections and RAPS systems based on PV/wind/diesel combinations. A new customer considering connection to the grid extension can model the costs of the power line, system losses and future maintenance costs. Transformers, retail tariffs and conductors can all be selected to suit the specific case. Economic perspectives are provided for the customer, the utility company, and the community as a whole. Cash flows, NPVs, unit costs of electricity and levelised annual costs are calculated. These can be compared with the costs of installing a RAPS system.

Other models have been developed to aid decisions such as the planning of an expansion to an autonomous energy system which includes renewables (Habouris and Contaxis, 1992). This model was based on meteorological data, load demand data and economic parameters. The user is able to evaluate the combinations of wind, PV and diesel generation over a given number of years. Planning and operational constraints were recognised in the model.

### **6.2.2 New Zealand experience**

A wide range of small scale renewable energy conversion technologies are commercially available in New Zealand. Some are locally manufactured such as wind turbines, solar water heaters, micro-hydro generators and wood gasifiers; others are imported including PV panels.

Selection, matching and installation of components is a somewhat specialist skill. There are many examples of do-it-yourself systems operating in New Zealand and few are thought to be operating at their optimum efficiency. Recently companies specialising in designing and installing RAPS systems have upgraded the standard expected.

New Zealanders have already played a role therefore in developing RAPS components and, given the right incentives, the benefits of further research and development could be substantial. For example, a recently established Oamaru company developed an efficient cross-flow micro-hydro turbine suitable for RAPS and partial grid power displacement, after one of the company directors noted the potential for micro-hydro while on a field trip to Fiordland. Diesel generators were being widely used there in spite of an abundance of water. The company now provides a turnkey service and employs nearly 10 full-time staff to build and install the micro-hydro units. The company manufactures the turbines and uses imported generators. The usual unit power output is 10 to 15 kW but units of up to 60 kW have been installed. The units are ideal for RAPS, but the cost is also becoming competitive with grid generation, especially where line charges are being raised to meet true cost.

Eventually more people currently connected to a utility network but who live in remote areas may need to consider a RAPS option. Under the current process of electricity reform, it seems plausible that remote users will eventually have to meet the full cost of the investment in and maintenance of power lines. The Rural



Electrical Reticulation Council (RERC) has confirmed that the Electricity Act (1992) makes it obligatory for supply companies to maintain all existing lines for at least 20 years. This period was set to give rural consumers time to adjust to the economic reality of distribution costs. Some power boards, such as Marlborough Electric, have made a commitment to upgrade all lines so they will be acceptable for the next 30 years. On the other hand, another power company director was quoted recently as saying it would make more commercial sense to cut out the lines to remote areas and sell them for scrap!

Some power boards are taking a more creative approach to line costs and RAPS. For example, Southpower faces the prospect of upgrading some rural lines to cope with growing demand. An economic alternative is to contain demand growth through a combination of energy efficiency initiatives and encouraging the use of alternative energy sources such as LPG and RAPS systems. Southpower is facilitating these steps. Several other power companies including Tasman Energy are assisting remote users within their area to evaluate RAPS options.

It is not known how many RAPS systems are operating in New Zealand or how successful they are. Certainly some micro-hydro schemes, such as the one providing power to the Dawson Falls Hotel on Mount Taranaki, have been operating successfully for decades.

Many systems were installed by enthusiasts rather than professionals. This continues in regions where no installers with specialist expertise exist. A list of suppliers and installers compiled by Tasman Energy Ltd contains 23 companies spread throughout New Zealand (Abeltshauser, 1995). Their level of experience and number of installations completed is not known.

The following case studies of successful RAPS schemes are outlined to show the range of applications possible.

### ***Case study 1: Micro-hydro on dairy farm.***

A dairy farmer taking over a new block had his house and shed located 2.4 km from the 11 kV line. Connection costs were quoted at \$48,000 and power charges were estimated to be around 10 c/kWh, including both energy and line maintenance charges.

A natural water supply on the farm was measured and gave a flow of 150 l/s. The head was over 30 m. A micro-hydro scheme was quoted as follows:

Turbine/generator set (30 kW)	\$12,000
Governor	\$6000
Reticulation	\$9600
Penstock and intake	\$16000
Installation	\$6000
	<hr/>
	\$49,600

The initial capital investment for both options was similar. The difference was in the annual costs. For the mains supply, these would be embodied in the power charge of 10 c/kWh, assuming this provided for maintenance of the line in perpetuity which is not certain. The annual maintenance cost of the micro-hydro scheme was taken to be \$300 per year. A ten-year life was assumed for the scheme, and a depreciation fund in the order of \$4700 per year would therefore need to be established. This indicates that power from the micro-hydro scheme would cost around 11 c/kWh net of capital. By the time tax depreciation was built in, and the likelihood acknowledged that a properly maintained RAPS scheme would probably not need a full replacement at the end of ten years, the micro-hydro option was estimated to yield cheaper power.

The final decision came to a choice between the potential cost savings against the reliability and convenience of the mains power. Many consumers would be willing to pay more for this greater convenience. Others would prefer to be independent from national power cuts and may make emotional rather than commercial decisions.

Of all the renewable energy sources, micro-hydro is probably the most reliable, with low maintenance



assuming it is properly designed and installed. In this case, the dairy farmer opted to install the micro-hydro scheme.

### **Case Study 2: PV/wind for rural trust dwellings**

A rural trust in Canterbury was quoted \$30,000 by the local power company to reticulate power 1.5 km to its building complex. Additional costs were considered to be switchboards, electrician's labour, energy charges and interest lost on investment capital.

Consequently, the following system was installed over a three year period:

6 x 60 W photovoltaic panels	\$4500
Inverter	\$3000
Regulator	\$500
Batteries 24 V, 187 Ah	\$1500
Diesel generator set (backup)	\$5000

Subsequently, the generator set was replaced by a 300 W Soma wind turbine and four extra PV panels were later added. The additional cost was:

4 x 40 W photovoltaic panels	\$3000
Wind generator	\$2000

In addition, a water wheel was installed to replace an electric water pump to provide water for irrigation.

Thus the total investment of approximately \$14500 was half of the grid connection quote. The labour for installation was not costed and 90% of the wiring, splitter boxes etc. was recycled to keep the costs down. The system provides for lighting, TV, radio, iron, washing machine and power tools in the small house. A fridge-freezer is used intermittently when excess power exists, which is "sufficiently often to be useful".

The regulator can accommodate another six power panels, which may be added in future "when we feel the need to". The battery bank will then need increasing from the current three days of storage assuming conservative power use. The current waterwheel may eventually power a small alternator as well as the water pump. The system is not perfect and would only suit this form of "sustainable lifestyle" where power is "conserved and cherished". It is low maintenance and has not developed any major problems to date. It is considered cost effective by the users in this situation as the renewables have completely replaced the diesel generation.

### **Case Study 3: Micro-hydro for tourist lodge**

The owner of a tourist lodge in the Marlborough Sounds investigated alternatives to a 15 kW diesel generator which was expensive to run, inconvenient, noisy and had insufficient capacity to enable expansion and improvements of the guest facilities. In 1985, the option to extend the mains 11 kV network a distance of 20 km to supply the lodge, four other permanent residents, and 31 holiday home owners, was quoted at \$716,000. Hence the area remained unreticulated.

The lodge required a reliable power supply, so a micro-hydro scheme based on a nearby stream was evaluated. Water flows of 20 l/s with a head of 56 m were deemed suitable to sustain a 5.8 kW plant without affecting the local environment. Water was diverted into an artificial storage dam to avoid problems of stream fluctuations (Figure 6.6). The overall cost of installing the automatic plant was \$39,000. The cost of energy produced was 17.7 c/kWh for the 32,000 kWh generated each year, which was cheap compared with 57.0 c/kWh using the old diesel generator.

Even though the system provides all the power needed most of the time, the diesel generator was retained as a back up, but is rarely used. If the area had been reticulated in 1985, the lodge's share would have been \$170,000, and annual power charges at \$2700 would have given an average unit price of 48.9 c/kWh. Hence, the payback of 3-4 years for the micro-hydro scheme was quite satisfactory.

The turbine installed was a Pelton wheel design with up to six nozzles and a full load flow of 16 l/s. The plant

provides electricity for lighting, fridge, freezers and kitchen appliances. Unused power is used to heat water or air. Cooking is by LPG and wood is used for space heating.

The project has been monitored under the Energy Management Demonstration Programme (EECA, 1991) and could be replicated by farms or small communities in isolated areas with a similar watercourse.

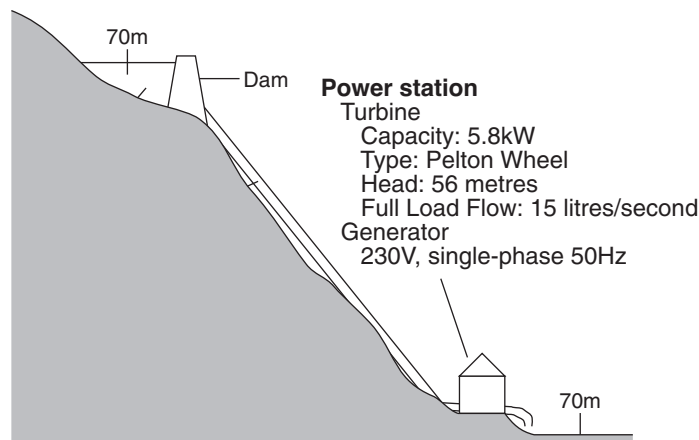


Figure 6.6: Micro-hydro scheme design for a tourist lodge in the Marlborough Sounds

#### Case Study 4: Island home and boat-shed

The ranger's home on Kapiti Island, a visitor's whare, and the boat winch are all supplied with power from a micro-hydro scheme. Originally diesel generators provided the 40-50 kWh/day, kerosene was used for refrigeration, wood for cooking, and LPG was used for space heating. Transporting all these fuels to the island was a major problem.

The boat winch provided the biggest challenge to the economic design of a RAPS system due to the high peak current of 70 A. Variable speed drives proved unsuccessful, so a 400 V motor speed controller was installed to reduce surges at start up and therefore allow a smaller size inverter to be used. A special 230-600 V DC doubler/converter was designed for the project. A direct bypass 400 V, 3 phase lead was connected to the 6 kW generator to be used in an emergency should the controller fail.

The house was converted to electric space heating, electric water heating, low energy light bulbs, and LPG for cooking. Pumps, fridges and freezers remained. The original load aim of 30 kWh/day was increased to 40 kWh/day to provide added convenience in the form of a dish washer and clothes dryer.

A 230 V, 10 kW sine wave inverter was used to provide quiet power 24 hours a day from the 120 V, 300 Ah battery bank. The controller monitors battery condition and load. It either dumps excess energy into a heater element or starts up the 6.25 kW diesel generator to supply any deficit.

The stream flow is over 200 l/min with a 65 m head. A 100 mm diameter penstock over 300 m gives only a very small pressure drop from 700 to 630 kPa. The turbine can be adjusted using a spear valve to suit changing flow rates in summer and winter. A 400 V, 3 phase, 1.5 kW self excited alternator was attached to the turbine and a rectifier converts the power to 120 V DC at the battery shed, 1 km from the generator. The battery charge is 33 kWh/day at this flow rate.

The diesel generator operates for around 3 h/day to generate 14 kWh to make up the deficit from the micro-hydro scheme.

The total capital cost was around \$70,000 including installation, transportation of components etc. Running costs for diesel fuel, LPG and maintenance are around \$3600/year. The fuel saving compared with using the original large diesel generator gives a 10 year payback period. However the quieter environment and added convenience are also benefits. Supply reliability means that digital clocks and pre-set video recorders can now be used which were not practical previously due to frequent power fluctuations whenever the generator started up.

### Case Study 5: Great Barrier Island residents

Great Barrier Island is 90 kms north-east of Auckland, and, at 285 km<sup>2</sup>, is the largest island off the North Island coast. The 1200 permanent residents and the holiday home owners have to provide their own energy supply, there being no reticulated power or gas. A study of the energy demand was recently undertaken (Wharton, 1995). It included a postal survey of residents giving a 49% response, 68 respondents being non-permanent holiday home owners and 96 permanent. Most of the information provided in the study related to firewood use following the Auckland City Council planning restrictions on the clearance of manuka and kanuka, the traditional firewood supply for heating and cooking. A summary of the energy sources used on the island is given in Table 6.1.

		Permanent residents	Holiday home owners
Cooking	Wood	53%	55%
	LPG	43%	64%
	Electricity	4%	0%
	Coal	0%	0%
Space heating	Wood	88%	70%
	LPG	21%	18%
	Electricity	3%	3%
	Coal	0%	0%
	Kerosene	1%	6%
	No heating	2%	14%
Water heating			
Main fuel:	Wood	71%	56%
	LPG	21%	33%
	Electricity	4%	0%
	Coal	0%	0%
	Kerosene	0%	3%
	Solar	4%	2%
	No water heating	0%	8%
Back-up fuel:	Wood	10%	8%
	LPG	16%	14%
	Electricity	7%	5%
	Kerosene	0%	3%
	Solar	6%	20%
	No back-up	61%	58%
Use electricity?	Yes	85%	34%
	No	15%	63%
Which source?	PV panels	38%	33%
	Wind turbine	15%	19%
	Diesel/petrol generator	45%	28%
	Micro-hydro	2%	0%
Source of firewood	Grown on property	55%	48%
	Collected elsewhere	23%	31%
	Purchased	23%	21%

**Table 6.1: Energy sources used by permanent residents and holiday home owners on Great Barrier Island.**

The non-permanent residents stay on the island nine weeks a year on average. Since this is mainly during the summer period their energy requirements differ markedly from those of the permanent residents.

A series of electrical generation cost models were developed in the study to ascertain the net present costs over a thirty year period based on a 9% discount rate, a diesel price of \$0.73/l, and petrol at \$1.13/l delivered. The generating systems compared are outlined in Table 6.2.

System	Specifications
Diesel	4.2 l diesel engine/3.6 kW generator 4 x 350 Ah batteries, 6V Inverter Total cost \$10,470 Fuel consumption 1.9 l/h
Petrol	4.0 l petrol engine/3.0 kW generator 4 x 350 Ah batteries, 6V Inverter Total cost \$8,130 Fuel consumption 2.0 l/h
Wind/solar	SOMA 1 kW wind turbine 4 x 75 W PV panels Regulator 24 deep cycle batteries Inverter Total cost \$23,167

**Table 6.2: Selected domestic generating systems to provide economic comparisons**

Fuel and maintenance costs were added to the capital costs depending on the appliances used and the number of days operated per year. It was assumed that for permanent residents space heating consumed 839 kWh annually, cooking 1300 kWh and water heating 4000 kWh. Other appliances common to all three systems such as lighting and TV consumed an additional 820 kWh per year.

The net present costs of each system are summarised in Figure 6.7 for residents and non-residents. The appliance investment costs were included being \$50 for a 1 kW electric bar heater with 15 year life; \$1079 for an electric stove with 30 years life; and \$529 for a low pressure, 135 litre, hot water cylinder with 15 year life. The range of net present costs reflects these capital costs and their annual hours of use. The “combined” category is for a household with an electric heater, stove and water heater.

The diesel generator was the least cost electrical source for all loads for permanent residents but wind/solar was only slightly more expensive. So the choice comes down to noise and exhaust emissions versus the greater inconvenience of wind/solar, which cannot be called on as and when required. For holiday home owners the total net present costs for diesel/petrol generators were cheaper due to the considerably lower use of the appliances and hence savings in diesel or petrol. The net present costs of solar/wind were the same as for permanent residents, there being no running costs involved for fuel. For permanent residents consuming a total of 7000 kWh/year for space heating, water heating, cooking, lighting, TV etc., the unit costs would be 20.8 c/kWh for diesel 34.4 c/kWh for petrol and 22.8 c/kWh for wind/solar.

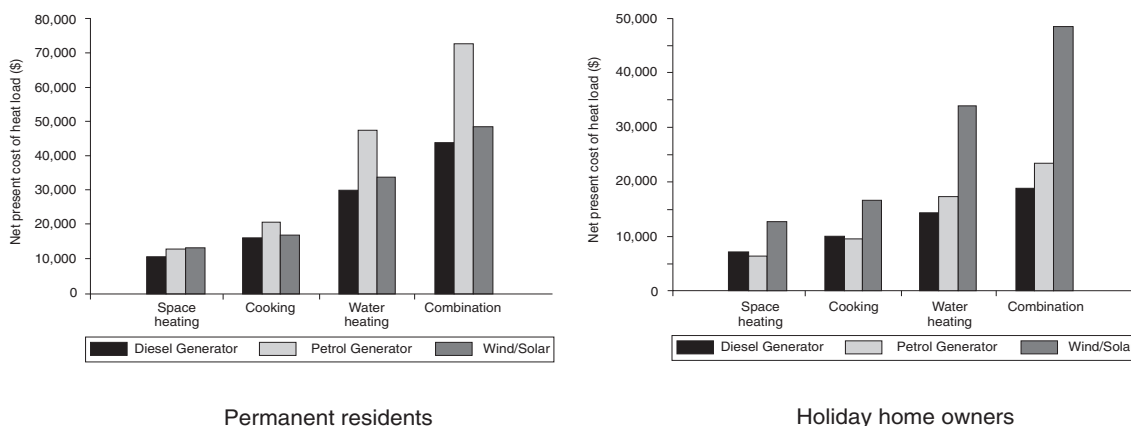
It would be of interest to take the study one stage further and identify trends towards or away from diesel generation by ascertaining from residents by interview survey the age of their system, its reliability, their satisfaction with it and the reasons or intentions for any changes.

### **6.2.3 Environmental and social aspects**

Displacing diesel fuel by greater use of PV and wind results in lower emissions. Embedded RAPS systems,

where the electricity generated is used locally, can avoid the need for unsightly overhead high voltage power lines.

Communities and organisations with independent energy supplies are often proud of their achievements in this regard. The identified public interest in “green” pricing of electricity is taken to its ultimate by independent energy users. Employment opportunities to manufacture, install and maintain small-scale energy systems are apparent. Local impacts would be site and technology dependent (see the technology section within the text), and could include the visual impact of the local RAPS system.



**Fig 6.7: Net present cost comparisons of three electricity generation systems to supply space heating, cooking, water heating or a combination of all three (Wharton, 1995)**

### 6.2.4 Economics

Autonomous energy systems tend to be capital intensive but benefit from free energy inputs from wind, solar radiation, water flow or waste organic matter for biogas plants. Energy storage costs need to be included in any cost analysis.

Each system has specific costs depending on components, location, scale, weather inputs, reliability level etc. The use of computer models helps to ascertain the unique optimum combination for a given site.

Total capital costs for a small domestic scale PV/wind/battery RAPS system are around \$2000 to \$5000/kW. Maintenance costs will be hundreds of dollars per year if battery replacement is included. It can be assumed operation input is free and carried out by the owner/consumer. To provide mains quality, reliable power, available 24 hours a day, at 230 V AC, will cost between 20 to 66 c/kWh. The cost of power from a PV system alone would be 45 to 65 c/kWh. A stand-alone wind system can produce power slightly cheaper than for a stand-alone PV system of similar output but the supply is less reliable. A combination would give improved reliability levels (Dienhart, 1995).

The cost of power from diesel generator sets varies with load factor and engine size but is in the range between 30 to 60 c/kWh. In the future it is possible that RAPS systems will become more economically viable against the use of high maintenance, stand-alone diesel gensets, if the diesel price increases or the RAPS component costs reduce as a result of mass production economies.

Typical examples of system component costs are given in Table 6.3 for a range of installations.

For any of the above RAPS systems, lower capital investment is possible if the user is prepared to compromise on quality and convenience. Attempts to cut costs however often result in long term problems that make the system ultimately more expensive in terms of additional maintenance costs and intermittent supply.

### 6.2.5 Constraints and opportunities

Independent power supply systems cannot compete with mains power where available, not only from the economic viewpoint but also with regard to the convenience and reliability of supply. Only hobbyists and enthusiasts can justify generating their own power if grid power is available.

(a) Holiday home

Electric demand for lights, TV, stereo = 1 kWh/day  
 1600 hours of sun per year; 5 h/day in summer; 50% power output when cloudy

2 x solar modules (4 A, 75 W)	\$1700
2 x 70 Ah batteries - (deep cycle, 12 V, 17 kWh)	\$500
Inverter - (400 W)	\$1200
Installation	\$500
	<hr/>
	\$3900

<u>OR</u> Petrol generator (600-1000 W)	\$2500
+ petrol for 2 hours running/day	\$300
1 x 150 Ah batteries - (deep cycle, 12 V, 1.8 kWh)	\$300
Inverter - 400 W	\$1200
	<hr/>
	\$4300

## (b) Small, low load, permanent home. Electric demand for lights, TV, VCR, stereo, was machine, microwave oven, refrigerator, freezer, power tools = 5 kWh/day

Stream with 20 m head on property.

Micro-hydro power generator (500 W)	\$3000
Installation	\$1000
2 x 200 Ah batteries (deep cycle, 12 V, 4.8 kWh)	\$800
Inverter - 3000 W	\$2600
Regulator	\$800
	<hr/>
	\$8200

<u>OR</u> Diesel generator (3 kW)	\$4000
+ diesel for 3-4 hours running/day	\$350
3 x 200 Ah batteries (deep cycle, 12 V, 7.2 kWh)	\$1200
Inverter/charger (3 kW)	\$3500
	<hr/>
	\$9,050

## (c) Tourist lodge or small community. Electric demand for lights, fridge, freezers, wash machines, dryer, pumps = 100 kWh/day.

Nearby hill top; mean wind speed = 6 m/s

Wind turbine (5 kW)	\$22000
Installation	\$3000
12 x 200 Ah batteries (48 V, 115 kWh)	\$6000
Inverter (10 kW)	\$15000
Charger (4 kW)	\$4000
Diesel generator (6 kW)	\$7500
+ diesel for running 12 hours/day	\$1800
Controls	\$3000
	<hr/>
	\$62,300

<u>OR</u> Diesel generator (12.5 kW)	\$18000
+ diesel for running 10+ hours/day	\$7000
10 x 200 Ah batteries (48 V, 96 kWh)	\$5000
Inverter (10 kW)	\$15000
Charger (4 kW)	\$4000
Controls	\$3000
	<hr/>
	\$52000

**Table 6.3: Small-scale electricity generation capital cost examples**

For remote users the choice is between diesel generators and renewables. Diesel is more reliable but possibly more expensive depending on the delivered fuel price. A combination system is a practical compromise. Opportunities exist due to anticipated power price increases, the high costs of power lines to service new rural buildings and technology continually improving to provide high quality power supplied on a reliable basis.

### **6.2.6 Future research requirements**

A market survey to ascertain current and future demand for autonomous energy systems would provide useful trend data. In addition a complete database of New Zealand suppliers, manufacturers, installers, together with components offered by each, would be of assistance to system designers.

A computer model system design package suited to New Zealand conditions should be developed and made commercially available.

An integrated system suitable for a “typical” domestic user with matched components and therefore not custom produced would help to reduce the capital costs.

Improved storage systems with higher efficiencies and lower costs should continue to be sought.

The addition of “intelligence” to the control system to enable statistical predictions of weather inputs to be made, depending on the time of year, and loads to be reduced as a consequence, would improve the effectiveness of the system from the convenience point of view.

A future energy supply option for rural communities faced with rising network connection and maintenance charges is the use of low capacity lines to bring power in to trickle charge individual or shared battery storage. Peak power demands could be drawn from the storage via an inverter. A small amount of local generation via a RAPS system could be used to augment the network supply. Storage and independent generation would save costs by avoiding the need to size the network connection lines to take peak demand. If these savings were greater than the cost of batteries, inverters, and other RAPS components, then the overall approach would be attractive. Further research is required.

Demonstration programmes for RAPS systems have been established in Australia and financial incentive schemes are available. A review of the current level of service and facilitation to potential RAPS users by power companies should be undertaken to ascertain whether demonstration and financial assistance programmes are warranted in New Zealand.

## **6.3 Future Vision**

Within ten years, and in response to technological development and increased awareness of environmental issues, New Zealand’s energy supply system is likely to change markedly. A quantum break from the past is possible. The future will not be a continuation of the past albeit better and more efficient. Increased power demand may not be met by new large-scale coal-fired power stations as some forecasters predict. Instead, by 2005 substantial movement towards the following directions is a reasonable proposition.

- Marked improvement in energy end-use efficiency/management technologies and practice.
- Minimal local network infrastructure with trickle feed to homes/offices.
- Distributed home- and office-based generation using PVs and solar thermal.
- Regions with light industrial loads largely reliant on embedded generation.
- Grid downsizing in such areas to match residual local network demands.
- Greater use of wood residues in embedded generation and to supply the grid.
- Development of a significant local wind turbine manufacturing industry.
- Trials with power transmission using superconductors.



## 6.4 References

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## ***Annex 6.1: Procedure for sizing components of a RAPS system***

The following example is based on the work of Weiss, (1992).

The components of a hybrid system must be sized correctly to ensure the right amount of energy is delivered on a monthly or annual basis to meet the energy demand. The optimum size of the various components is largely influenced by their respective costs in relation to their energy contribution. The magnitude of the various renewable energy resources for a specific site has a major influence of the most appropriate size combination. In combination with a price analysis, this can be used to determine which renewable energy source is the cheapest.

### ***Procedure***

- Step 1: The demand, and its variability on a monthly and preferably daily basis, is specified.
- Step 2: The most promising single energy source is chosen to meet the power demand calculated in step 1 (solar power, wind power, or micro-hydro) and the size of the required system is then calculated.
- Step 3: The system is priced, the cost annualised, and divided by the energy demand to obtain a \$/kWh figure. Associated running and maintenance costs must be included.
- Step 4: The amount of battery storage required is determined. This is then priced and annualised. A cost per kWh for the battery storage capacity is calculated as for step 3 above.
- Step 5: The cost in \$/kWh calculated in step 3 is added to that calculated in step 4 to obtain the total cost (\$/kWh) of meeting the demand by the single energy source.
- Step 6: The next most favourable energy form or a diesel generator is selected. The proportion of the total energy demand to be met by this secondary energy source is arbitrarily allocated.
- Step 7: Step 3 is repeated for the original energy source but for the reduced amount of the energy produced. Step 3 is repeated again for the secondary energy source and the two costs added together.
- Step 8: The reduced battery capacity requirement is calculated. A new cost per kWh of battery storage is then calculated.
- Step 9: A cost for the extra control and regulation equipment required for the hybrid system is determined. Adding this figure to those derived from steps 7 and 8 results in the total cost to meet the demand with this particular combination.
- Step 10: The proportion to be contributed by each energy source is altered and steps 6 to 9 repeated until the final \$/kWh result is minimised.

### ***Hybrid sizing example***

Assumptions:

A steady demand of 6 kWh per day

4 days storage required

5% discount rate used

Photovoltaic array cost of NZ\$13 per peak watt

Cost of stand-alone 1.5 kW wind turbine = \$14,000

Cost of 0.5 kW wind turbine used in hybrid system = \$8,500

\$200 per year maintenance spent on both stand-alone and hybrid systems

Additional control system cost in hybrid system of \$1,500

Turbine life of 20 years

Photovoltaic array life of 15 years

Array output kept constant during the year by altering tilt angle to match the sun elevation.

Battery life of 10 years

Maximum depth of battery discharge = 50%

Overall battery efficiency of 85%

Life of control equipment of 20 years

***System A: Using solely wind power to meet the demand***

Step 1: Wind turbine selected:

Cut-in wind speed: 4 m/s

Rated wind velocity: 12 m/s

Cut-out wind velocity: 20 m/s

Rated output: 1.5 kW

The amount of power produced by the above turbine at a site with a mean annual wind speed of 5 m/s is 3,060 kWh per year.

Step 2: The cost of the turbine is \$14,000.

Annual maintenance and running costs \$200.

Using the discount rate of 5%, over 20 years, the annualised fixed cost of the turbine is \$1,120.

Total cost is  $1,120 + 200 = \$1,320/\text{year}$

Amount of useful energy per year equals the daily demand times

$$365 \times 6 = 2,190 \text{ kWh}$$

$$\$1,320 / 2,190 \text{ kWh} = 60 \text{ c/kWh}$$

Step 3:

$$\text{Storage capacity required} = \frac{4 \text{ days}}{\text{days}} \times \frac{6 \text{ kWh}}{\text{daily demand}} \times \frac{1}{0.5} \times \frac{1}{0.85} = 56.5 \text{ kWh}$$

depth of  
discharge      battery  
efficiency

Total cost based on a battery cost of \$500 per kWh

$$56.5 \times \$500 = \$28,250$$

Annualised battery cost = \$3,659

Storage cost/unit =  $\$3,659 / 2,190 \text{ kWh} = \$1.67/\text{kWh}$

Therefore, the total cost of meeting the demand with this particular turbine and battery combination

$$0.60 + 1.67 = \$2.27/\text{kWh}.$$

**System B: The hybrid system**

Step 1: Assume 60% wind power and 40% photovoltaic power based on site weather data.

Step 2: Calculate the energy cost for both wind and PV.

Wind turbine selected:

Cut-in wind speed: 3 m/s

Rated wind velocity: 11 m/s

Cut-out wind velocity: 15 m/s

Rated output: 0.5 kW

For a site with a mean annual wind speed of 5 m/s, the turbine produces 1,420 kWh per year (averaging 3.9 kWh per day). Only 3.5 kWh per day is needed based on the proportions between wind and solar estimated in step 1.

Annualised cost = \$680

Plus annual \$200 maintenance = \$880/year

Amount of useful energy produced is 3.5 kWh x 365 = 1278 kWh per year.

Generation cost/unit = \$880/1278 kWh = \$0.69/kWh

Photovoltaic cells selected:

\$6,500 was spent on photovoltaic cells @ \$13 per peak watt (500 Wp rated system).

Average radiation conditions on site are 5 kWh per day per m<sup>2</sup>.

500 Wp would therefore deliver 5 x 500 = 2.5 kWh per day.

Annualised cost = \$625

Annual useful output = 2.5 x 365 = 913 kWh.

Generation cost/unit = \$625 / 913 kWh = \$0.68/kWh.

Step 3: Revised Storage Requirement

The original storage period for wind power alone was 4 days, which required 56.5 kWh of storage capacity. During this same period, 2.5 kWh per day x 4 days = 10 kWh is likely to be contributed by the photovoltaic array.

$$\text{Storage capacity required} = \frac{10 \text{ kWh}}{\text{depth of discharge}} \times \frac{1}{0.5} \times \frac{1}{0.85} = 23.5 \text{ kWh}$$

Therefore, with the hybrid system, only 33 kWh (56.5 - 23.5) storage is required.

Total cost = 33 x \$500 = \$16,500

Annualised cost = \$2,137

Storage cost/unit = \$2,137/2,190 kWh = \$0.98/kWh

Step 4: Cost of Control Equipment

Additional control equipment cost (\$1500) annualised = \$120

Total annual energy = 2,190 kWh

$$\text{Control costs/kWh} = \$120 / 2,190 \text{ kWh} = \$0.055/\text{kWh}$$

Step 5: From the above costs/kWh, the total cost of supplying power with the wind-photovoltaic hybrid will be:

$$\{0.69(3.5/6)\} + \{0.68(2.5/6)\} + 0.98 + 0.055 = \underset{\text{wind}}{0.40} + \underset{\text{solar}}{0.28} + \underset{\text{battery}}{0.98} + \underset{\text{controls}}{0.055}$$

$$= \$1.72/\text{kWh}$$

$$\begin{aligned} \text{Savings from the hybrid wind/PV scheme over the sole use of the 1.5 kW wind turbine} &= \$2.27 \\ - \$1.72 &= \$0.54 \text{ per kWh} \end{aligned}$$

In order to derive the optimum size combination of the various elements of a hybrid system, this procedure should be undertaken using a spreadsheet iteration to derive the least cost option, but maintaining an acceptable degree of reliability.

## ENERGY EFFICIENCY AND CONSERVATION AUTHORITY

The Energy Efficiency and Conservation Authority (EECA) is an independent government agency charged with delivering and implementing practical measures for achieving greater energy efficiency in New Zealand.

It was established in 1992, is governed by a Board and is responsible directly to the Minister of Energy in the development of its strategies and programmes.

The following functions are specified in the Authority's terms of reference:

- To develop, implement and promote strategies for energy conservation, and
- To advise the government and the New Zealand energy industry on matters relating to the development, implementation and promotion of those conservation strategies, and
- To monitor known energy sources, their use, and the investigation of potential sources and applications, together with the economic, social and environmental impacts, in both the short and long term.

The specific outcomes which EECA outputs contribute to are:

- The wise and efficient use of New Zealand's energy resources through improved energy management and the application of energy efficiency technologies having regard to environmental and social impacts. The strategies employed will improve long term energy security and economic growth, and reduce greenhouse gas emissions.

The Authority is vitally concerned with maximising the sustainability of New Zealand's use of energy. Its focus and activities embrace all energy consuming sectors and technologies, all fuel types and emerging renewable energy resources. It seeks to develop practical technical solutions, and implement innovative marketing programmes, to meet the challenge of improving energy use.

Above all the Authority is a facilitator. It seeks to achieve its goals in partnership with other organisations. Its activities are designed to build the market for energy services. "Enlightened co-operation" is the theme which underlies most of its programmes.

For further information on EECA contact:

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*Chief Executive: Martin Gummer*

## CENTRE FOR ADVANCED ENGINEERING

The Centre for Advanced Engineering was founded in May 1987 to mark the centenary of the School of Engineering at the University of Canterbury.

The objective of the Centre is to enhance engineering knowledge within New Zealand in identified areas judged to be of national importance and to engage in technology transfer of the latest research information available from overseas. The Centre is not concerned with basic engineering research, but with the application of research findings to engineering problems.

The Centre undertakes major projects, bringing together a selected group of practising and research engineers and experts in the particular field from both New Zealand and overseas to:

- consolidate existing knowledge
- study advanced techniques
- develop approaches to particular problems in engineering and technology
- promote excellence in engineering
- disseminate findings through documentation and public seminars.

The Centre also facilitates joint publications with other organisations, carries out smaller projects on engineering subjects of current concern, and arranges lectures and seminars on appropriate topics as the occasion arises.

For further information on the Centre's activities and publications, contact:

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# ***New and Emerging Renewable Energy Opportunities***

***in New Zealand***

New Zealand is a unique country with its own particular factors tending to make conditions favourable for many specific renewable energy applications. The country has abundant resources of wind, water, sunshine and land to grow crops.

Over the next 10 to 15 years, energy from traditional sources may become increasingly scarce and expensive, and there is likely to be increasing international pressure to limit carbon dioxide emissions into the atmosphere. Such factors are likely to make a variety of sources of renewable energy increasingly attractive.

Also, the national grid at present transmits large amounts of electricity over long distances with consequent energy losses and vulnerability to natural hazards, both of which could be reduced by having more renewable energy available close to the point of use.

This report outlines the technology, economic viability and environmental impact of various types of "non-traditional" renewable energy systems for implementation in New Zealand.

This report includes:

- solar energy systems;
- biomass energy systems;
- water energy systems; and
- wind energy systems.